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OBSERVATIONS ON THE AGE AND GROWTH OF THE NORTHERN PIKE, *ESOX LUCIUS* L., IN EAST HARBOR, OHIO

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INTRODUCTION

The recent interest in the northern pike, found along the Ohio shores of Lake Erie, has prompted a series of studies designed to obtain information on the best possible management and utilization of this species.

East Harbor is a sand-spit pond separated from Lake Erie by a large sand bar. A channel permits Lake Erie water conditions and fish populations to influence those of the harbor. East Harbor has a surface area of about 850 acres, of which the larger portion, under normal water conditions, is less than 8 ft in depth. The area contains an abundance of underwater vegetation, chiefly *Myriophyllum* spp., marshes of cattail, *Typha* spp., along the west and south shores, and an abundance of marginal vegetation which is inundated intermittently in accordance with the storms or strong winds on Lake Erie. A small ditch which drains a limited area of orchard is the only tributary stream; and its level is controlled by that of the harbor and the lake. The bottom in both the harbor and the stream is chiefly soft organic debris and silt.

MATERIALS AND METHODS

This study is based on scale samples taken from 688 pike during the month of March, in the years 1951 through 1953, as a part of a tagging program to provide information on the movements of these fish. The fish were taken in 6 ft modified fyke nets which are used as standard test net equipment in Ohio's fisheries operations. These nets are composed of 2 in. square mesh in the leads, 1 and ½ in. in the hearts, and 1 in. in the cars.

Total length measurements are used in Ohio and measurements to the nearest one-half in. were recorded. Calculations were made to the nearest tenth-inch in calculating the lengths at each annulus.

Since the pike were taken in March, an annulus was assumed on the farthest edge of the scales. In a few instances, an annulus was present on the edge of scales of pike which were completing their first year of growth; but none were found on the scales of the older fish.

RESULTS AND DISCUSSION

Age

The histogram (fig. 1) portrays the percentage distribution of the 688 northern pike arranged according to the age groups. The range in the 1951 sample indicates a well distributed group of age classes in which the four year old fish represented 25 percent of the total sample. The 1952 catch reveals a large number of two year olds (21%) entering the population, and a reduction in the older four to six year age classes found in 1951. The 1953 sample further illustrates the

continued reduction of the older groups, found in 1951, and their replacement with younger ones, chiefly the three year olds.

The maximum ages of pike from East Harbor were 10 years for 4 females and 8 years for 4 males. Maximum ages of 15 years in Lake Waskesiu, Saskatchewan, was reported by Rawson (1932).

Growth

The growth rates of the individuals varied greatly (fig. 2). Calculated lengths at the formation of the first annulus ranged from 2.9 to 19 in. This age group averaged 15.8 in. at the time of capture as compared to the average calculated total length of 11.4 at the formation of the first annulus (table 1). These data and the data presented in figure 2 indicate that the information on the younger age groups may be a selected set of data resulting from the sizes of the net mesh. No pike under 12.5 in. were retained in the nets. Carlander (1953) lists a range from 4.1 to 21.1 in. in length for northern pike in age group one. Northern pike reared in the St. Marys Fish Farm, Ohio, have ranged from 3 to 23 in. in length at 5 months of age. Actual total lengths tend to vary when good or poor growth occurs in certain years, whereas it is our opinion that calculations tend to absorb or smooth out such deviations from the averages.

Since all scale samples were collected in March, the date of annulus formation was not ascertained. However, these samples were collected prior to the time that the annulus formation is suspected to occur. Thus, the total lengths exceeded considerably the calculated average lengths of the fish at the formation of the annuli. For example, those fish whose scales contained two annuli averaged 20.1 in. at the time of capture; but the calculated length at the formation of the second annulus was 17.2 in. If the annulus formation takes place shortly after the season during which these pike were taken, as was taken for granted in assuming an annulus on the edges of the scales, these fish were almost three years of age. Thus, their average total lengths at capture should closely approximate the average calculated lengths of pike at the formation of the third annulus. The 20.1 in. in length at capture compares favorably with the 21.2 in. average calculated length at the formation of the third annulus. This average length at capture is 94 percent of the calculated length at the formation of the next annulus. In all age groups but the first, the average total lengths at the time of capture represented from 92 to 98 percent of the total calculated length at the formation of the next annulus.

According to the data presented in table 1 and figure 3, the greatest growth of both sexes was made in the first year of life. The calculated length of the males slightly exceeded that of the females at the formation of the first annulus (table 1). The lack of an equal number of both sexes may account for this difference. The average calculated annual increment of males was about 106 percent that of the females during the first year of life, 94 percent the second, 70 percent the third, 71 percent the fourth, 63 percent the fifth, 73 percent the sixth, 66 percent the seventh, and 88 percent the eighth. Carbine (1942) and Solman (1945) reported that female pike grow more rapidly than males.

EXPLANATION OF FIGURES

FIGURE 1 (top, left). Age group distribution of the East Harbor northern pike taken in the years 1951, 1952 and 1953.

FIGURE 2 (top, right). Average maximum, average and minimum total lengths of East Harbor northern pike at the end of each year of life.

FIGURE 3 (bottom, left). Rate of growth and increment of East Harbor northern pike at the end of each year of growth.

FIGURE 4 (bottom, right). Growth histories of male and female northern pike from East Harbor. The lines connect points representing average lengths attained in ages indicated by the Roman numerals.

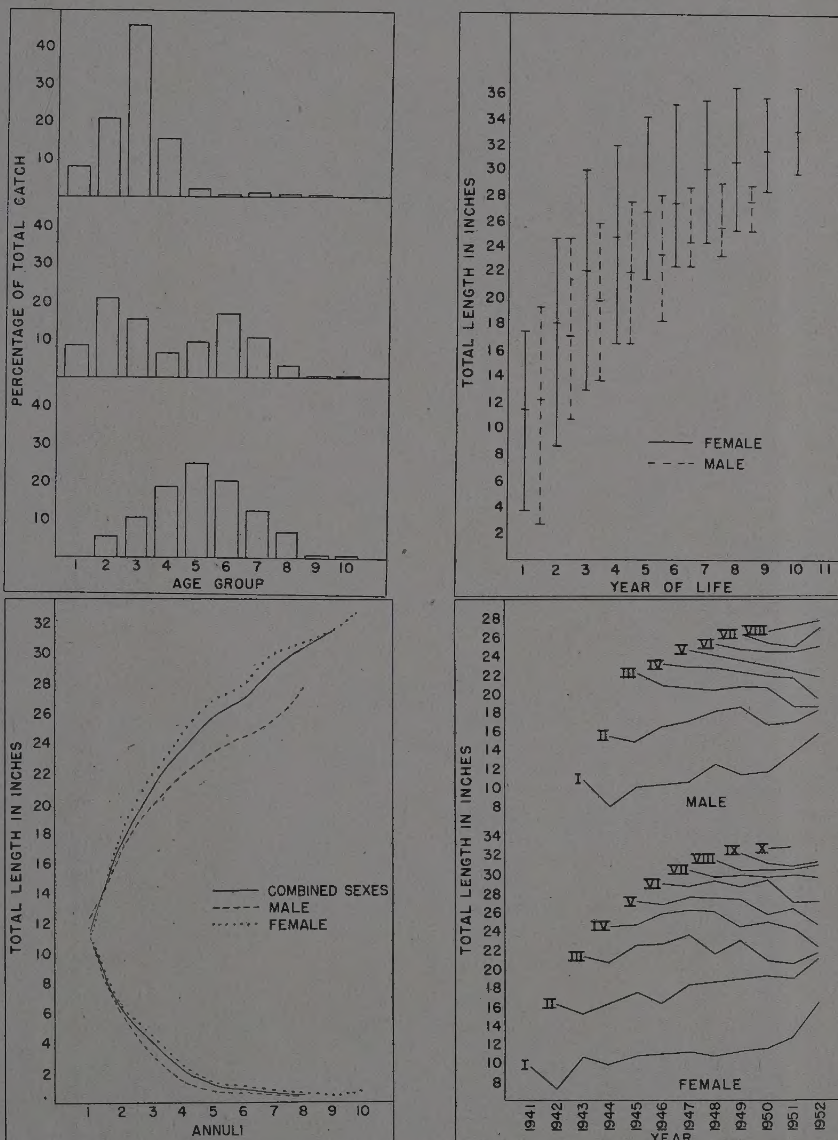
PERCENTAGE OF TOTAL CATCH
AGE GROUP
TOTAL LENGTH IN INCHES
YEAR OF LIFE
FEMALE
MALE
TOTAL LENGTH IN INCHES
ANNULI
COMBINED SEXES
MALE
FEMALE
TOTAL LENGTH IN INCHES
MALE
FEMALE
YEAR
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952

TABLE 1

Average calculated total length, in inches, attained by East Harbor northern pike, of age groups 1 through 10, at the end of each year of life

Age group	Number of specimens	Sex	Year of life 1	2	3	4	5	6	7	8	9	10
10	4	Female	9.5	15.9	21.1	25.7	27.4	29.2	30.4	31.5	32.1	32.8
9	8	"	8.8	16.7	21.7	24.8	26.8	28.5	29.4	30.1	30.7	
8	19	"	10.0	16.8	22.6	25.6	27.9	29.1	30.0	30.7		
	4	Male	10.4	16.1	21.8	24.1	25.3	26.1	26.8	27.5		
7	33	Female	10.2	17.9	23.1	26.0	27.8	28.9	29.7			
	18	Male	10.5	16.5	20.8	22.7	23.7	24.4	25.0			
6	45	Female	11.1	18.3	22.3	24.7	26.3	27.1				
	23	Male	10.4	17.5	20.7	22.3	23.5	24.3				
5	42	Female	10.8	18.5	22.1	24.3	25.6					
	32	Male	10.6	16.8	19.8	21.5	22.4					
4	64	Female	10.9	17.1	21.2	23.1						
	32	Male	10.9	17.0	19.8	21.3						
3	115	Female	11.7	16.7	21.6							
	74	Male	11.8	16.5	19.3							
2	64	Female	12.6	21.3								
	54	Male	11.7	18.7								
1	5	Female	16.4									
	52	Male	15.7									
Average calculated length		Female	11.3	18.0	21.8	24.4	26.7	27.4	29.8	30.4	31.2	32.8
		Male	12.0	17.2	19.8	21.8	23.2	24.1	25.3	27.5		
		Combined	11.4	17.6	21.2	23.6	25.5	26.4	28.6	30.1	31.2	32.8
Average annual increment		Female	11.3	6.4	4.5	2.4	1.6	1.1	.9	.8	.6	.7
		Male	12.0	6.0	3.1	1.7	1.0	.8	.6	.7		
		Combined	11.6	6.3	4.0	2.1	1.4	1.0	.8	.7	.6	.7

TABLE 2

Average annual growth increment, in inches, of East Harbor northern pike by calendar years, 1941 through 1952

Year of life	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952
		Male northern pike										
8										.7		.4
7									.9	.6	.6	.5
6								.7	.8	.9	.7	.5
5							.9	1.1	1.2	.7	.5	.6
4						1.5	2.0	1.8	2.1	1.4	1.5	1.7
3					6.5	5.9	3.8	3.0	2.3	2.0	2.3	3.0
2				4.6	7.0	7.1	6.5	7.5	7.0	5.1	4.9	6.0
1			11.0	8.0	9.7	10.7	10.7	11.5	11.5	11.9	13.7	15.9
Number of specimens			2	6	20	34	30	22	27	80	44	24
		Female northern pike										
10										.6	.8	
9									.6	.6	.5	.4
8								1.2	.7	.6	.4	.8
7							1.3	1.1	.7	1.0	.7	.7
6						1.8	1.6	1.2	.9	1.9	.6	.5
5					1.8	2.4	1.5	1.7	1.4	1.1	1.7	.8
4				3.9	3.8	3.0	3.4	2.6	2.8	2.3	2.3	1.8
3			5.3	5.5	6.2	5.3	4.2	3.4	4.2	5.9	4.1	5.1
2		6.3	7.9	5.8	7.5	8.4	7.2	7.4	7.9	6.0	5.9	8.4
1	9.9	7.8	9.4	9.9	10.7	10.8	11.0	10.7	11.1	11.2	12.9	16.4
Number of specimens	3	4	12	27	33	49	31	21	61	113	41	4

Annual growth increments of male and female northern pike of the various year classes (table 2 and fig. 4) illustrate that the annual growth of fishes of the same age varies from year to year, and for different age groups in the same calendar year. To illustrate this point, a comparison of the increments of the hatch of 1949 and 1950 can be made with that of the other year groups in table 2. The 1949 and 1950 hatches, in their first years of growth, closely approximate the average calculated increments listed in table 1 for both sexes. Yet, both sexes reveal increments which would indicate poor growth in their second year of life. If pike depend chiefly upon sight for feeding, the high and turbid waters in the early summers of 1950 and 1951 may have seriously affected the feeding and growth of the second year fish. Yet, these factors may have had little detrimental effect, and possibly a beneficial one, on the hatch of the year in the flooded and clearer backwaters of the marshes. As reported by Carbine (1945), slow growth in one year does not destroy the growth potential for other years. A seven year old male was calculated to have grown only 2.9 in. in its first year. However, it measured 27 in., or 1.7 in. over the average for others of its age when captured. This was one of the largest males taken during the study.

TABLE 3

Average total lengths at successive annuli of East Harbor, Ohio northern pike compared to that reported from other waters

Location of water area	Number of specimens	Annuli 1	2	3	4	5	6	7	8	9	10
Minnesota waters*	2,621	7.8	13.2	17.7	21.1	24.2	26.8	29.0	31.1	33.1	35.1
Illinois waters†	72	9.9	17.5	21.0	23.6						
Wisconsin waters†	528	10.0	18.0	23.0	27.0	30.1	33.0	36.0	38.0	40.0	44.0
Ohio waters, present work	688	11.4	17.6	21.2	23.6	25.5	26.4	28.6	30.1	31.2	32.8

*Kuehn 1949.
†Van Engle 1940.

Van Engle (1940) and Miller and Kennedy (1948) presented data which indicated that the increased growth rates in southern waters were associated with a decrease in the life span in northern pike. Table 3 reveals that growth of East Harbor northern pike and those of Illinois exceeded that reported from more northern waters, except for the Wisconsin data. Greeley (1940) reported from Lake Ontario growth of northern pike which closely paralleled that found for those from East Harbor, but reported his data for age groups, not at the end of each year's growth.

SUMMARY

Scale samples from 688 northern pike taken from East Harbor, Ohio, during the month of March in the years 1951 through 1953, were used in this study. Growth was calculated on the assumption of direct proportion between scale measurements and the lengths of the fish at the time of annulus formation. An annulus was assumed on the farthest edge of the scales.

Pike from age groups one through ten were taken; but numbers of the older groups were small.

Calculated growth for individuals of the same age varied greatly. The selectivity of the net mesh may have influenced the data for the younger fish.

The greatest annual increment was found in the first year of life and was followed by an annual decrease thereafter.

Sexual dimorphism, so far as females appearing to grow more rapidly than males in a given period of time, was evident.

Calculated annual increments for fish of the same age was found to vary from year to year, and for fish of different age groups in the same year.

The growth of East Harbor northern pike compares favorably with that reported from other waters. The more rapid growth in the younger fish and the suggested short life span for East Harbor pike are in keeping with reported data on the inverse variation of growth with latitude and the correlation of rapid growth and decreased life spans.

Maximum ages of ten years in females and eight years for males is suggested by this study.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance and guidance of Dr. Kenneth Carlander, Department of Zoology and Entomology, Iowa State College, in the preparation of the manuscript, Mr. Darrell Allison, of the Ohio Division of Wildlife for compiling the tables, and the fisheries personnel of Wildlife District Number 2 who conducted the field operations.

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Ecologists have concentrated on two approaches to their problems. The autecologists have been studying the species as a unit, while the synecologists have studied whole communities. Moore considers these to be but two legs of a tripod, and the integral ecology is needed to combine the components into a whole field. He presents this synthesis in his consideration of marine ecology, with excellent sections dealing with physical, chemical, and biological factors, habitats, and the organisms which occur in each of the major types of habitat.

An appendix lists all genera referred to in the text and a fine series of references. The index is excellent; the format is pleasing; and the figures are well selected. More photographs would have added value, but the text is clear and well presented.

THOMAS H. LANGLOIS

GLACIAL OUTWASH TERRACES OF THE HOCKING AND SCIOTO RIVER VALLEYS, OHIO

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A study of the outwash terraces of the Hocking and Scioto Valleys has led to some interesting facts which aid in unraveling the glacial history of south-central Ohio, particularly the Scioto lobe of the Wisconsin stage. This paper is an attempt to relate the various terrace systems of both valleys to each other and to the fluctuations of the several glaciers which covered the central part of Ohio during the Pleistocene. It also should aid future workers in dating and correlating the terraces of the Ohio River Valley, into which outwash materials from the Hocking and Scioto Valleys were carried.

The area studied (fig. 1), in south-central Ohio, follows the valleys of the Hocking and Scioto Rivers and portions of two of their major tributaries, Clear Creek (Hocking) and Paint Creek (Scioto). Detailed study of the Scioto Valley outwash was not carried north of Circleville in Pickaway County but may be found in reports on Pickaway County (Schuster, 1952) and Franklin County (Schmidt, 1958).

Reference has been made to the outwash in the major valleys of Ohio many times by geologists. The outwash has been used, particularly, as evidence of the age of drainage changes which have taken place along the major streams in southeastern Ohio. A good summary and a complete list of references on the work done on these drainage changes up to 1943 can be found in Stout et al. (1943). Andrews (1860) was probably the first to mention outwash in southern Ohio valleys. Tight (1900, 1903) studied the drainage changes in southeastern Ohio with some mention of the outwash in the valleys. Others who have referred to the presence of outwash in the valleys include Andrews (1874), Stearns (1899), Leverett (1902, 1942), Hyde (1912), Stout and Lamb (1938), and Foster (1950). Hyde (1921) discusses, in some detail, Illinoian and Wisconsin outwash in the Scioto Valley within the Camp Sherman Quadrangle, and Merrill (1950, 1953) has defined various levels of Illinoian and Wisconsin terraces in the Hocking Valley within Hocking County. Outwash terraces in the Hocking were studied even more extensively by Kempton (1956). Hubbard (1954) has given a brief summary of terrace relationships in the Ohio, Muskingum, Hocking, and Scioto River Valleys, and indicates the presence of Illinoian and Wisconsin outwash in both the Hocking and Scioto Valleys.

Hocking Valley Terrace Systems

Five terrace systems appear to be present in the Hocking Valley. Since they fall into three groups both by level and soil, they may represent as many as three stages of Pleistocene glaciation. These terrace systems have been identified mainly by soils (fig. 4) and by plotting profiles based on the elevations of each terrace segment (fig. 3). Stonecounts were of aid in stratigraphic identification of the two lowest terrace systems.

Pre-Illinoian stage.—Although pre-Illinoian glaciation extending to southern and southeastern Ohio has not as yet been definitely established, two lines of evidence in the Hocking Valley point to such a glaciation.

Two terrace remnants composed of strongly weathered sand and gravel with a strong red color are present in the Valley. Both contain a mixture of foreign pebbles. One of these, about two and one-half mi west-southwest of Logan in Hocking County (fig. 2), lies between Dry Run and Clear Fork (SW ¼ Sec. 16

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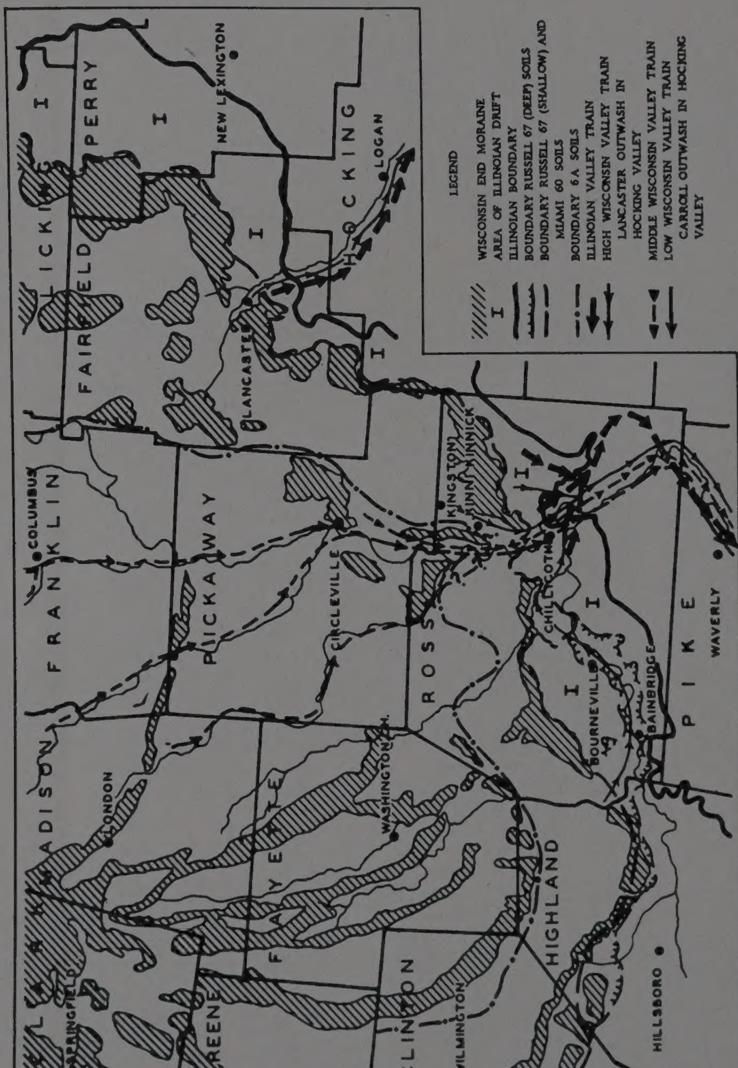
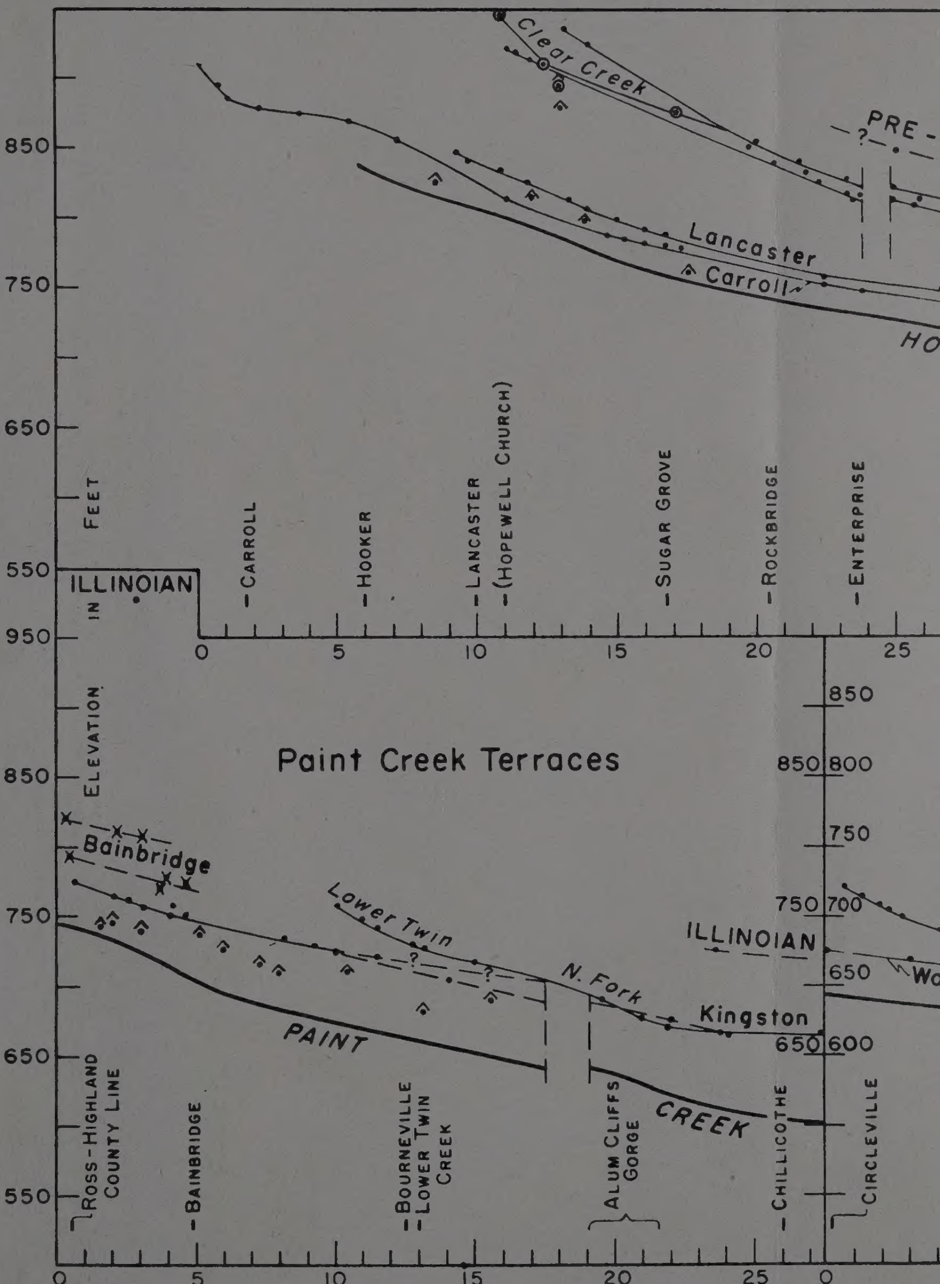
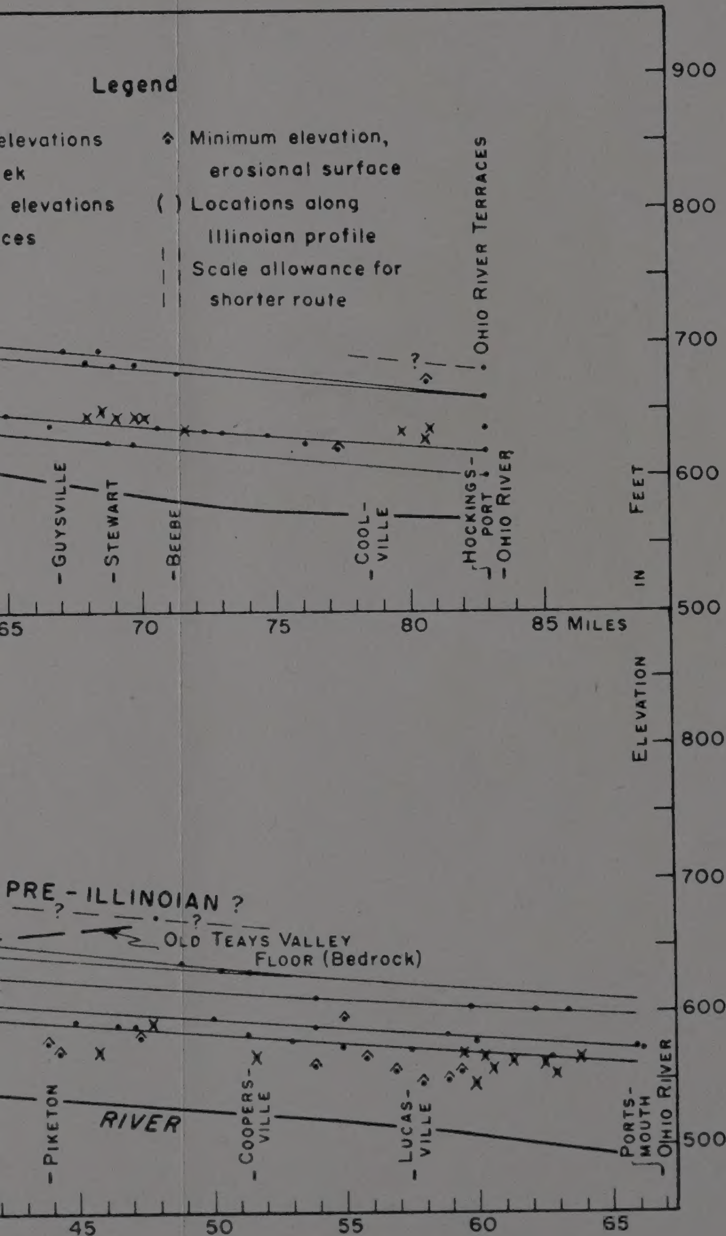


FIGURE 1. Glacial geologic map of central Ohio, showing portions of Scioto and Hocking Rivers and major tributaries.



Paint Creek Terraces
ELEVATION IN FEET
ILLINOIAN
Clear Creek
PRE-
Lancaster
Carroll
HO
CARROLL
HOOKER
LANCASTER
(HOPEWELL CHURCH)
SUGAR GROVE
ROCKBRIDGE
ENTERPRISE
Bainbridge
Lower Twin
N. Fork
Kingston
ILLINOIAN
PAINT CREEK
Wa
ROSS-HIGHLAND COUNTY LINE
BAINBRIDGE
BOURNEVILLE
LOWER TWIN CREEK
ALUM CLIFFS GORGE
CHILLICOTHE
CIRCLEVILLE


Legend
elevations
ek
elevations
ces
Minimum elevation, erosional surface
( ) Locations along Illinoian profile
Scale allowance for shorter route
OHIO RIVER TERRACES
GUYSVILLE
STEWART
BEEBE
COOL-VILLE
HOCKINGS-PORT
OHIO RIVER
900
800
700
600
500
65
70
75
80
85 MILES
ELEVATION IN FEET
PRE-ILLINOIAN ?
OLD TEAYS VALLEY FLOOR (Bedrock)
PIKETON
RIVER
COOPERS-VILLE
LUCAS-VILLE
PORTS-MOUTH
OHIO RIVER
45
50
55
60

Falls Township). The surface of this remnant is somewhat rounded with the highest part at an elevation of 850 ft, at least 23 ft higher than the highest of several extensive Illinoian terraces in the immediate area (fig. 3). The other patch of gravel is located within the bend of the Hocking Valley about one mi south of Coolville and two and one-half mi northwest of the Ohio River on the east bank (fig. 2) and is well exposed along State Route 144. Profiles projected from the Illinoian terraces in the vicinity of Stewart indicate that the maximum elevation of this remnant may be slightly higher than the Illinoian outwash at this point (fig. 3).

The red soils developed on each remnant are similar to those formed under long subtropical weathering conditions. In each case only local sandstones, rotten igneous and metamorphic, and siliceous rock types are present, embedded in a sticky clay-rich matrix. Calcareous or unoxidized gravel was not exposed at either locality, but leaching and oxidation have progressed to a depth of at least 15 ft in both cases.

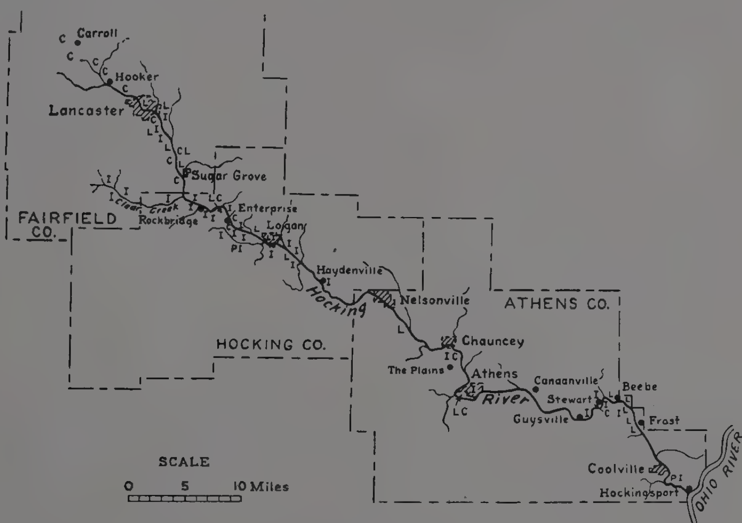


FIGURE 2. Map of Hocking River and portions of major tributaries, showing approximate location of larger terrace remnants: PI, pre-Illinoian; I, Illinoian; L, Lancaster; C, Carroll.

Merrill (1950, 1953) described erratics high on the hills above Rockbridge, considering them mainly Illinoian terrace remnants. However, the profile of the Illinoian outwash, traced from the source area in Fairfield County, falls at a level much lower than the elevation of most of these erratics. Since there is yet no conclusive evidence of Illinoian ice having advanced as far as Rockbridge, it remains a possibility that some of these erratics are the only remaining traces found thus far of pre-Illinoian ice or water-laid deposits.

Illinoian stage.—Two terrace systems are present in the Hocking and Clear Creek Valleys which are interpreted as representing outwash deposited during the Illinoian stage of glaciation. These terraces constitute the most numerous and extensive outwash deposits preserved from Lancaster in Fairfield County to the Ohio River in Athens County (fig. 2). Especially notable are the extensive areas of smooth-topped terrace between Rockbridge and Logan and "The Plains" just

northwest of Athens. Since both are in abandoned sectors of the Valley where the present Hocking flows in a narrower, somewhat longer course than that occupied by the Illinoian outwash, breaks have been necessitated in the Illinoian profile in figure 3.

The profile of the Illinoian terraces (fig. 3) indicates that there may be two terrace systems at least at the upper (north) end of the valley. Although elevations of most terrace segments group around one profile, a great difference in elevation between segments just south of Lancaster suggests two stages of outwash deposition. Also the slight but consistent variations in elevation, up to 20 ft down the valley to Beebe, is suggestive of two levels. However, the levels may have converged at some point between Rockbridge and the Ohio River, with subsequent erosion obscuring the exact area of convergence. Differentiation of two levels on a soils basis was impossible due to the great length of time during which soil development has progressed.

The soils developed on the Illinoian terrace remnants (fig. 4) are deep, having been leached an average of 15 ft and oxidized as much as 20 ft. Up to five ft of yellow-brown silt and fine sand (loess) are present over the weathered gravel on some terraces. These soils, called Park (or Hocking) are generally dark reddish-brown to yellowish-brown in color. Most of the upper five ft is clayey (B horizon), and contains only rotten and decomposed igneous, metamorphic, and siliceous pebbles and occasionally carbonate pebble "ghosts." In most deep exposures, cementation of the gravels by secondary carbonate produces large projecting blocks below the leached zone.

Counts of 100 one to three in. pebbles from nine Illinoian terrace remnants along the valley averaged 37 percent carbonate and associated rocks, 39 percent local sandstones and shales, and 24 percent crystallines, but great deviation occurred in four of these counts. Carbonate analyses of the sand, silt, and clay fractions from the outwash of eleven Illinoian terraces yielded an average of 22.4 percent total carbonate content with only three samples deviating much from the average and ranging 5.5 to 32.0 percent.

The bases for relating the outwash terraces described above to the Illinoian stage are: 1) the 20-ft depth and clayey character of the soils developed on the terraces; 2) much higher elevation (40 to 90 ft) of both terraces in relation to the Wisconsin terraces; 3) depth and extent to which the original surface has been trenched in both the main and local valleys; 4) tracing of the terrace systems to their sources just inside the Illinoian drift border; and 5) steepening of gradient from about 4 ft per mi downvalley to about 13 ft per mi at the Illinoian border.

Probably the most reliable means to date these terraces was tracing them to their source inside the glaciated area of Fairfield County. Two principle source areas are indicated by the field mapping (fig. 2): one near Lancaster in the Hocking Valley and one just east of Clearport in Clear Creek Valley. There may have been a third source near North Berne, east of Lancaster and down Raccoon and Rush Creeks, but this has not been mapped in detail. The terrace systems in all valleys head inside the Illinoian drift border (fig. 3) as mapped by Leverett (1902), White (1939), and more recently by Conley (1956).

The major source of outwash appears to have been in the vicinity of Lancaster at the beginning of the narrow bedrock restriction of the Hocking Valley. Two terrace levels are present, the highest at an elevation of 935 ft, begins about two and one-half mi down the valley from Lancaster on the west side of the valley while the lower heads at an elevation of 920 ft at the southeastern limits of the city. The valley train of Clear Creek probably headed about one mi southeast of Clearport at Hopewell Church and entered the Hocking Valley at the higher Illinoian level about two mi northeast of Rockbridge in northern Good Hope Township, Hocking County (fig. 2 and 3).

Wisconsin stage.—Two low terrace systems comprise the valley train deposits

which have been laid down in the deep trench cut into the Illinoian valley train. Merrill (1953) made no specific distinction between these two terrace systems although he does indicate at least two levels on profiles.

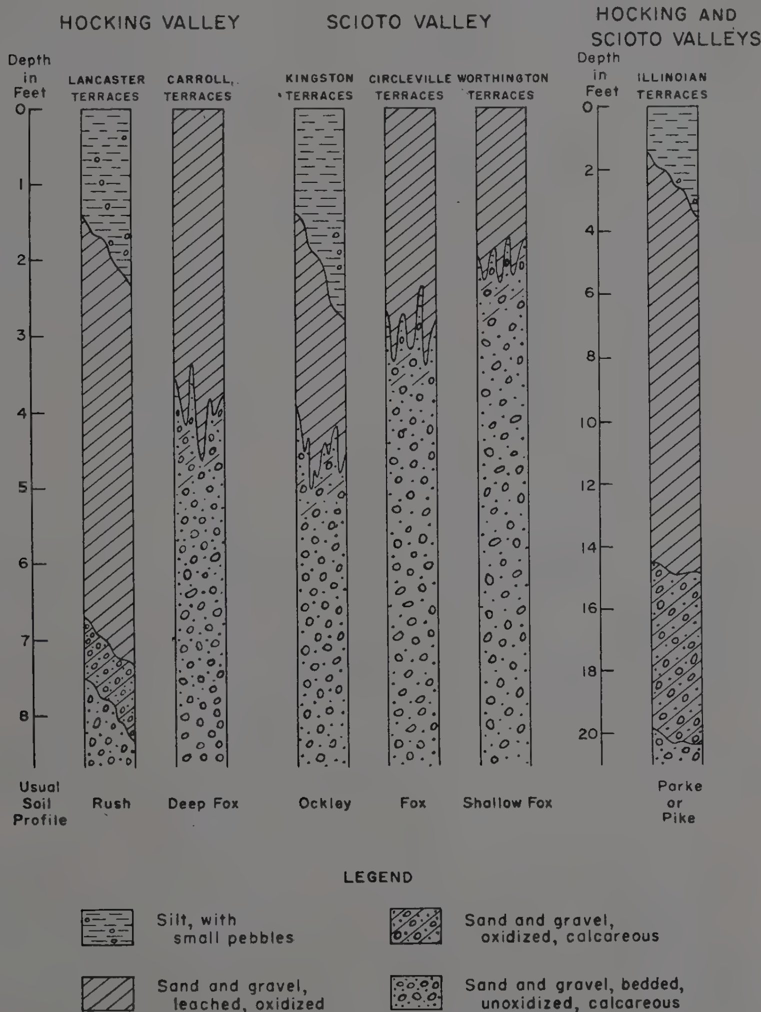


FIGURE 4. Generalized diagrams of terrace soils.

The higher of these two terrace systems heads at Lancaster in Fairfield County, at the outer edge of the Wisconsin terminal moraine, and is found at various points along the Hocking Valley to about six mi from the Ohio River (fig. 2). Much of the City of Lancaster rests on this terrace. For this reason it will be called the Lancaster terrace system.

The soil developed on the Lancaster terrace (fig. 4), particularly in Fairfield and Hocking Counties, are deep, with a characteristic chocolate-brown color. This is probably Rush type soil. In most cases a light brown pebbly silt covers the gravel to a maximum thickness of two and one-half ft. Oxidized gravel generally extends to a depth of about eight to ten ft below the surface. Where the original smooth surface is preserved, the depth of the leached zone generally extends to about 90 in. below the surface. In Athens County, below the City of Athens, the aspects of the soil and terrace materials change somewhat. The composition of the outwash becomes finer and is interbedded with thin layers of blue-gray clays. The soil is deeper, with the materials oxidized and leached as deep as 20 ft.

Identification of remnants of this terrace system was aided by stonecounts of a hundred one to three in. pebbles which consistently gave counts varying only a few percent from: 46 percent calcareous rocks, 38 percent clastic (mostly local sandstone and shale), and 15 percent crystallines. Carbonate content of everything smaller than 2 mm averaged 26.1 percent. Most of the terraces which retain constructional surfaces fall on a fairly smooth profile (fig. 3). In one instance where a terrace remnant was not easily identified, information from a local resident indicated that an old gravel pit had been abandoned because there was too much overburden to remove.

An excellent exposure of a terrace of the Lancaster system is situated in a gravel pit at the northwest edge of Logan (NE ¼ Sec. 10 Falls Township, Hocking County) in the mouth of a small tributary valley to the Hocking. The evelation of its surface is 748 ft.

	Ft	In.
4. Yellow-brown silt and fine sand, contains many small pebbles	1	8
3. Sand and gravel, oxidized, dark reddish brown to chocolate brown, clay rich, many rotten pebbles, pebbles range up to ten in	5	2
2. Sand and gravel, oxidized, chocolate brown, calcareous, clayey with many rotten pebbles	3	2
1. Sand and gravel, gray to brown, unoxidized, many rotten pebbles, calcareous, a few lenses of leached gravel present, base not seen	20±	0

This exposure is typical of the Lancaster system above Athens. Below Athens a typical exposure occurs in a road cut about three mi east of Stewart, in the extreme southeast corner of Sec. 3 Rome Township, Athens County.

	Ft	In.
5. Gray-brown fine sand and silt	1	0
4. Fine sand, yellow-brown	4	0
3. Alternate layers of fine and medium sand, dark yellow-brown to chocolate brown	10	0
2. Coarse to medium sand, chocolate brown, clay rich, two 2-in. layers of hard gray-brown to tan clay interbedded with sand, leached to base	5	0
1. Gray, coarse to medium sand, containing numerous small pebbles under ½ in., calcareous, base not seen	5	0

The gradient of the Lancaster terrace system throughout its entire length averages about three ft per mi. The upper 13 mi has a gradient of seven ft per mi and gradually steepens at the head in the vicinity of Lancaster to 16 ft per mi. This indicates that the source of the outwash was probably at Lancaster.

The lower of the two low terrace systems heads further northwest in kames

and kame moraine about two mi northwest of Carroll, Fairfield County. It begins as a kame terrace, merges into an outwash plain and then becomes a valley train at Lancaster. Patches of this terrace system are present at scattered localities along the valley as far as Stewart in Athens County, southeast of which it apparently has been completely removed. It is called the Carroll terrace system for exposures at its head near Carroll.

The Carroll outwash contains a high percentage of calcareous gravel as indicated by three stonecounts. These show that the pebbles from the gravel average 67 percent calcareous and associated rocks types, 24 percent clastic, and 9 percent crystalline, very different from both the Illinoian or Lancaster terraces. Carbonates in the sand-silt-clay sizes were also higher, averaging 29.9 percent (ranging from 19.2 to 38.5 percent).

Exposures of the soil developed on the constructional surface of the Carroll terrace are rare, particularly in Athens County. Thus, numerous auger borings were used to supplement information from the exposures and to identify the terraces on a soils basis. A most pronounced feature of these soils is a wavy pendantlike line separating the leached, clayey, reddish-brown B horizon from the little-oxidized calcareous sand and gravel (fig. 4). The depth of leaching and clay concentration (B zone) varies greatly in a short distance due to the pendants, but generally averages about 48 in. in the upper part of the valley in Fairfield and Hocking Counties. In Athens County the depth of leaching is generally greater than 50 in. The soil itself consists primarily of dark reddish-brown oxidized clay-rich sand and gravel with an average thickness of 41 in. overlain by about seven in. of gray-brown sandy silt (A zone). The color and composition of the soil, including the pendants, are typical of the Fox catena. However, they are somewhat deeper than typical Fox soils, which usually range from 27 to 40 in. (leaching).

A typical exposure of the Carroll terrace soil and gravels is present in a gravel pit along a narrow portion of the valley about a mile north of Enterprise (SW ¼ NE ¼ Sec. 31 Marion Township, Hocking County).

	Ft	In.
6. Sand and gravel, dark reddish-brown, clayrich, noncalcareous	3	10
5. Sand and gravel, gray-calcareous, with oxidized, noncalcareous pendents numerous extending from zone 6	1	0
4. Silt and fine sand, gray-brown, calcareous	0	6
3. Sand and gravel, gray, calcareous, oxidized pendents numerous, noncalcareous	1	6
2. Silt and fine sand, gray-brown, calcareous, massive	1	10
1. Sand and gravel, gray, calcareous, with a few large cobbles up to two ft across, base not seen	14	0

Distinguishable remnants of these terraces are scarce below Logan (Hocking County), and thus the nature of the original outwash profile below Logan is questionable.

Lacustrine deposits.—Sediments consisting primarily of silt and clay are associated with the terrace systems in the valley. These deposits are present in many valleys tributary to the Hocking and also at numerous localities in the lower part of the Hocking Valley itself below Athens.

The lake sediments in the lower Hocking Valley are generally present in the form of flat-topped terraces along the main valley walls. The same type of sediments is also present in the tributary valleys in this area, such as Federal Creek. Paschall et al. (1938) mapped the soils developed on these terraces as the Wyatt silt loam. Where typically exposed, these deposits are blue, massive, calcareous, fine silt and clay, with occasional laminated beds present. Size analyses

of many samples of these deposits show that they contain no more than 5 percent sand. Small calcareous concretions up to one-fourth in. in long dimension occur in some of the massive deposits below the soil zone. Carbonate content ranges from 21 to 71 percent. Depths of leaching range from 26 in. to 52 in., with 26 to 36 in. the most common.

The close association of these lacustrine deposits with the Lancaster terraces points to deposition of both during approximately the same interval of time. The tops of the lacustrine terraces range from about 630 to 645 ft in elevation, which is the same range as the Lancaster terraces in the area. Also, Lancaster terrace remnants in this area contain many interbedded layers of clay and silt similar to the lacustrine clay and silt. From this evidence, it appears that while the lower Hocking drainage system was ponded (mechanism as yet not understood), outwash was building up progressively down the valley below Athens into a lake as a shallow delta. Sand and gravel was deposted during times of excessive discharge from the melting ice at Lancaster, and finer material was deposited while little or no outwash was being carried down the valley.

Above Athens, lacustrine deposits are present in several of the tributary valleys to the Hocking. An excellent example is the valley of Oldtown Creek which contains silt, clay, sand, and marl up the valley for several miles from Logan. Most of these valleys were ponded one or more times as outwash building up in the Hocking Valley blocked the mouths of these streams (Merrill, 1950).

Scioto Valley Terrace Systems

The Scioto Valley contains three outwash terrace systems of Wisconsin age, clearly separated from two high systems of Illinoian age. As in the Hocking Valley, the systems are identified by profiles (fig. 3) and soils (fig. 4). Stone-counts generally do not differentiate the various levels of outwash except to substantiate former connection of a few adjacent Wisconsin terraces. Detailed mapping of the Scioto Valley terraces was limited by time. However, a reconnaissance of the whole outwash drainage together with unpublished county studies establishes a fairly accurate picture of the valley train deposits.

Illinoian stage.—Illinoian outwash occurs as large, generally flat-topped remnants over an extensive area east and southeast of Chillicothe (fig. 5). These remnants are present along and between the small valleys of Lick Run, Dry Run, and Walnut Creek, along the east side of the Scioto Valley opposite Chillicothe, and in the abandoned preglacial Teays Valley in the vicinity of Londonderry and Vigo. Others extend southward to Richmondale in the Scioto Valley about two mi north of the Ross-Pike County line. Illinoian outwash appears to be absent along the Scioto Valley just north of Higby. However, there is a rather prominent remnant of Illinoian outwash near the mouth of Paint Creek to the north, as well as scraps present along a small valley in the western part of Chillicothe and along the Scioto Valley wall just west of town. This suggests that the main Illinoian outwash or entire flow passed eastward down the now abandoned old Teays Valley at Vigo.

Along the Scioto between Higby and Waverly, extensive plains of Illinoian outwash averaging about a mile in width cover an area of more than five mi^2. These terraces cover the bedrock floor of another isolated lateral segment of the old Teays Valley along the western flank of the present Scioto Valley. At Waverly the northward sloping bedrock surface of the Teays Valley apparently is just above the Illinoian outwash, the two profiles crossing at about 650 ft elevation just northeast of Waverly (fig. 3). Southeast of Waverly (fig. 5) the old Teays Valley lies in a broad bend with a gradual rise in elevation of the bedrock floor (Lockwood, 1954) so that no definite evidence of Illinoian outwash can be found.

Down the present Scioto River, between Waverly and Portsmouth, Illinoian outwash is represented only by small rounded knobs and a few narrow flat-topped

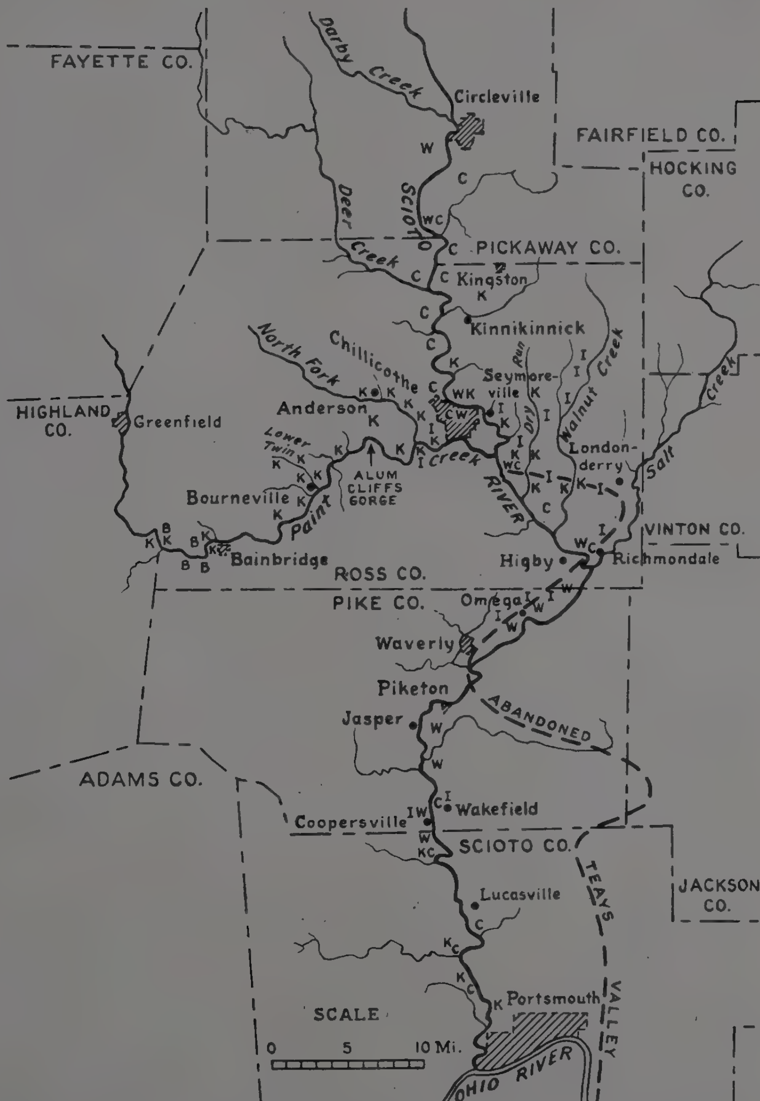


FIGURE 5. Map of lower Scioto River and portions of major tributaries, showing approximate location of larger terrace remnants: I, Illinoian; B, Bainbridge; K, Kingston; C, Circleville; W, Worthington.

remnants along the sides of the valley; considerable difficulty is encountered in locating them.

Patches of water-laid material, including calcareous sands, were found at elevations too high to be considered Illinoian (fig. 3). These may be deposits of the Teays River or the northward flowing preglacial tributary of the Teays, the Portsmouth River, which flowed in essentially the same position as the present Scioto south of Piketon (Stout et al., 1943). However, the possibility that some of this material is glacial, but of pre-Illinoian age, cannot be overlooked.

As in the Hocking Valley, there is evidence of two levels of Illinoian outwash (fig. 3). Both Hyde (1921) and Leverett (1942) mention two levels. The higher terrace level may be present along Walnut Creek far east of Chillicothe, but it is more apparent on the eastern side of the Scioto Valley just opposite Chillicothe where it heads at an elevation of 875 ft at the settlement of Seymoreville. This is thought to be a kame terrace though no kettle holes remain. The rather maturely-dissected remnants of this level extend for about five mi south of Seymoreville along the eastern side of the Scioto Valley. The lower level heads along Walnut Creek and also in lower Paint Creek west of the Scioto Valley. It is present as scattered narrow remnants southward along Walnut Creek to the abandoned Teays Valley in which an extensive southeastward sloping pitted outwash plain is developed. The kettle holes are only obscure shallow filled depressions in the field but are very obvious on aerial photographs.

Although the profiles indicate two levels continuing down valley, the identity of two surfaces is lost, particularly below Waverly, and they may converge as suggested for the two Illinoian levels in the Hocking Valley (fig. 3). Between Higby and Waverly two levels are present, the higher, close to the bedrock walls, being about ten ft above the more extensively developed lower surface. The fact that exposures and wells show that the bedrock floor is only 20 to 30 ft below the entire gravel terrace would tend to eliminate the alternate explanation of settling, such as might be expected in a deeper gravel fill.

The major portion of the Illinoian outwash is composed of fairly coarse sand and gravel. In general the higher outwash level heading at Seymoreville is composed predominantly of rather silty sand with some gravel while the lower level outwash appears to be composed of much coarse and cleaner sand and gravel beds. This distinction has not been noted south of Londonderry.

The depth and character of the soils (fig. 4) developed on these terrace remnants, where exposed or interpreted from well logs and auger borings, appears similar to soils developed on the Illinoian terraces in the Hocking Valley. About a mile west of Londonderry the following sequence is exposed in the lower terrace level (Goldthwait, 1955):

	Ft
4. Weak upper soil profile in silts (loess) "early" Wisconsin	3–5
3. Buried gray A-zone of humic gley in sands, Sangamon	2
2. Reddish B-zone, Sangamon, leached	6
1. Calcareous sandy gravel, Illinoian	3–9

There is some suggestion that the higher terrace is more deeply leached and oxidized. This was noted by Hyde (1921). But, as in the Hocking Valley, the total length of time during which all soil formation has progressed renders differentiation of substages on this basis difficult, particularly with the apparent different mechanical compositions of the parent outwash material of the two levels.

The bases of relating these high terrace systems to the Illinoian stage is the same as for the Hocking Valley. The source of these systems is inside the limits of the farthest advance of Illinoian ice into the Teays Valley in Ross County but not within Wisconsin drift limits. As indicated by figure 4, the soils developed on the outwash remnants are considerably deeper than on terraces of Wisconsin

age, but are similar to the soils developed in the Illinoian outwash of the Hocking Valley. Also, the elevations of the Illinoian terraces are 20 to 190 ft higher than the highest of those emanating from the area of Wisconsin drift to the north. This indicates an interval of erosion of the Illinoian valley train prior to the deposition of various Wisconsin valley trains. The greater steepness of the gradient of nearly 30 ft per mi, toward the source of the outwash in the bedrock hills east of Chillicothe, is indicative of nearness of the ice, and since only Illinoian ice-laid deposits have been recognized within the hills, the outwash also must be regarded as Illinoian in age. (It might be noted that Hyde [1921] postulated an "early" Wisconsin age for the lower Illinoian level, based primarily on what appeared to him to be deeper weathering of the higher level along with the more mature dissection. The lower level appeared to him to be less dissected, with a shallower weathering profile and preservation of a pitted surface in places. It is felt here that the finer texture and poorer sorting of the higher level outwash may give the impression of a deeper weathering profile. Also greater initial slopes of the higher level may have initiated more rapid erosion than on the broad flat lower level, thus leaving the higher level in a more advanced stage of dissection at present.)

Illinoian outwash is also mapped west of Bainbridge along the Ross-Highland County line above Paint Creek (Foster, 1950) heading at an elevation of about 975 ft. It was carried southward into the area now called Beech Flats near Cynthiana and possibly into the Baker Fork-Ohio Brush Creek drainage. There is no evidence of a connection with Scioto River drainage.

Wisconsin stage.—Three levels of outwash and a possible fourth originating from within the Wisconsin drift boundary are identified in the Scioto Valley and several tributaries (fig. 3). These terrace levels are generally readily distinguished north of Chillicothe but become more difficult to identify between Waverly and Portsmouth. Together they form a suite of profiles well below the level of the Illinoian terraces.

A local system of silt terraces (Bainbridge) is found just west of Bainbridge in the Paint Creek Valley (fig. 5). Falling some 165 ft below the Illinoian terraces and 50 ft above terraces with good Wisconsin Fox soil profiles these are believed to be of "early" Wisconsin age. Careful acre-by-acre mapping of the soils by the Ohio Division of Lands and Soil Survey (Petro, personal communication) indicate the presence of affiliated "early" Wisconsin till and ice contact deposits south and east of Bainbridge. Since there is no extension of this level down valley and because grains are of lacustrine size, these are thought to represent slackwater deposits accumulated in "early" Wisconsin time along decaying ice which squeezed into both ends of Paint Creek Valley. Nearby mollusc bearing lacustrine deposits at Humboldt (Reynolds, 1959) confirm a lake, and deep Williamsburg soils in the silt confirm preconventional Wisconsin age. At 1.7 mi west of Bainbridge an auger hole penetrated eight ft of this soil and silt, then passed again into reddish weathered sand; this is interpreted as Sangamon soil under a silt terrace remnant.

The highest extensive Wisconsin terrace system heads in eastern Ross County at a kame terrace group about two and one-half mi southwest of Kingston and east of the Scioto Valley at an elevation of 725 ft (figs. 3 and 5). For this reason it is called the Kingston terrace. It appears to join an esker chain which is present in discontinuous segments along the eastern side of the Scioto River beginning just south of Columbus. Various lines of evidence suggest that the terrace system is actually younger than the esker and not genetically attached; the esker extends past the terrace near Kingston toward ice contact deposits south of Kinnickinnick. Near Kingston there are a few tiny kettles suggesting proximity to ice and lack of matching high terraces west of the Scioto is argument for ice contact in this area. Patches of this terrace system are present along the eastern side of the Scioto Valley from three mi north to about five mi south of Chillicothe and in the valleys of Walnut Creek and possibly Dry Run entering from the east and Paint Creek

entering from the west (fig. 5). The remainder of the length of the Scioto Valley apparently contains only small remnants of the Kingston terrace system although positive identification is impossible due to the scarcity and small size of the remnants present.

Identification of remnants of the Kingston system in the Scioto Valley in the vicinity of Chillicothe was based on the presence of an Ockley soil: silt over gravel, with a reddish-brown clayey B horizon and an irregular pendant structure at the base of the leached and weathered gravel (fig. 4). The capping of silt and fine sand averages about 18 in. although as much as 30 in. occur at a few localities. The depth of leaching and oxidation was generally about 50 to 60 in., including the silt capping. The soils developed on the Kingston outwash level in Paint Creek differ from those along the Scioto near Chillicothe in that the former lack the fine silt and sand capping and have a deeper brown color, with a more gradational change from the weathered to unweathered sand and gravel. Depths of leaching here generally range from 36 to 48 in.

In addition to soils, the elevations of the terraces aid in the identification of the Kingston system (fig. 3). The terraces in Paint Creek Valley are somewhat complicated for representation on this profile due to outwash fan building from Lower Twin Creek Valley, the presence of the narrow Alum Cliffs Gorge diversion, and the moraine and outwash block at the northeast end of the old valley, near Anderson. In these areas the Kingston terraces with Wisconsin Fox soils fall into two levels. Some higher ones near Bourneville tie to sloping terraces up Lower Twin Creek and seem to project to the broad outwash crest at the valley mouth south of Anderson; presumably this water came down Lower Twin Creek and passed to North Fork Paint Creek after the ice freed this northerly route. A level about 20 ft lower (projected) comes from west of Bainbridge and may have passed through Alum Cliffs Gorge although it is possible that it merged with the upper level east of Bourneville. A terrace preserved at the lower end of the gorge indicates that some outwash took this route, with a final merger into one Kingston level at the present junction of North Fork and Paint Creek.

The material of the Kingston outwash system is composed of medium and coarse sand and gravel. In the Scioto Valley approximately 75 to 80 percent of the one to three-in. pebbles are calcareous rock types while in Paint Creek Valley the count is close to 90 percent, predominantly dolomite. No logs were available from wells drilled in these terraces and, thus, there is not stratigraphic information available suggesting the maximum thickness of the outwash.

The outwash, which comprises the terraces of intermediate Wisconsin level, here named Circleville, heads at the southeastern edge of Circleville in Pickaway County at the outer margin of the Marcy moraine. At its source the Circleville terrace is a rather extensive pitted outwash plain. Numerous kettle holes, large and small, are visible over much of the first four mi of the sloping surface. From Circleville to about eight mi south of Chillicothe, smaller terrace remnants are numerous and cover considerably more area than those of the other Wisconsin outwash systems. The main business district of Chillicothe city rests on this terrace. The only tributary which contains outwash of the intermediate level is Deer Creek in Northern Ross County. This apparently is present only as one remnant on the north side of Deer Creek Valley near its junction with the Scioto River in Ross County.

Remnants of this middle outwash system were identified mainly by their position on the profile (fig. 3) and by the soil character and depth of leaching (fig. 4). The diagnostic soil characteristics are a reddish-brown, clayey B horizon with a sharp, irregular pendant structure at the base. Total depth of oxidation and leaching averages 34 in. and varies from about 30 to 40 in. due to the pendants.

The outwash materials of this system are composed of sand and gravel, with

cobbles up to 10 to 12 in. not uncommon. It differs from Kingston terraces by its lack of loess cover. As in the case of the other terrace levels in the Scioto Valley, no unique pebble count identified this level; there were about 75 to 80 percent of carbonate pebbles among one hundred, one to three in. in length. Well logs record sand and gravel at least as deep as 117 ft under the surface of these terraces in the vicinity of Chillicothe, with no stratigraphic break indicated.

The lowest terrace system in the Scioto Valley is traced to just north of the junction of the Olentangy River with the Scioto at Columbus in Franklin County. Terraces of this level head near the Powell Moraine; remnants may be present as far north as Worthington along the Olentangy River and thus, it will be called the Worthington terrace system. Outwash of the same level and age appears to be present also in the valley of Big Darby Creek, and its tributary Little Darby, which enters the Scioto from the northwest at Circleville and also in the valley of Deer Creek (fig. 5). Patches of these low terraces are generally large and rather numerous between Columbus and the Ross-Pike County line, but further south are smaller and fewer in number.

The soils are similar to those developed on the intermediate terrace level, but differ in depth; the average depth of leaching and oxidation depth is 24 in., with a variation of from about 20 to 32 in. (fig. 4). As in the case of the other terrace systems, elevations of presumed remnants of this system plotted down valley aid in their identification (fig. 3).

Silt terraces.—Several silt terraces are present in the main Scioto Valley south of Chillicothe, particularly in Scioto County. They fall generally below the level of the Worthington terraces, although a few are present at or above this level (fig. 3). These might ordinarily be considered cut-and-fill terraces, as found in numerous places both in the Hocking and Scioto Valleys, but certain aspects raise a question as to their origin and age. These terraces generally consist of at least seven to nine ft of highly weathered acid silt and fine sand overlying sand and gravel. In a pit at the Pike-Scioto County line the upper one to three ft of the underlying gravel was generally oxidized and noncalcareous. The same acid silt and fine sand are also present over much of the floor of the valley of Walnut Creek and perhaps others. Markland catena soils are mapped here.

One critical exposure at the settlement of Coopersville, (west bank of Scioto River, extreme south edge of Pike County) displays sand and gravel (probably Worthington terrace) over silt. The lack of well logs in other areas near exposed silt deposits has made it impossible to determine whether or not similar silt underlies the gravels of the outwash terraces elsewhere. The lack of siliceous grit makes it appear that the silt and sand has not been derived from the intense weathering of sand and gravel, so it may be more reasonable to consider these terraces as floodplain deposits derived from the erosion of acid soils and rocks in the vicinity. These must have been formed in Sangamon or earlier time.

Lacustrine deposits.—Lacustrine deposits were noted mainly in the valleys tributary to the Scioto south of Chillicothe and in Paint Creek Valley as previously mentioned. These deposits are present in the valleys of Salt Creek, north of Richmondale, and in many other valleys to the south. They apparently were formed when one or more of the Illinoian or one of the Wisconsin valley trains dammed these valleys. These deposits consist of massive to finely laminated beds of clay, silt, and sand.

The valley of Indian Creek, a tributary to the Scioto Valley from the southwest about three mi south of Chillicothe, contains a very interesting lacustrine deposit exposed between Massieville and its mouth. The construction of a new highway (U. S. 23) has recently provided excellent exposures of varved clay which apparently accumulated during the time when an ice tongue, extending down the main Scioto Valley, blocked the mouth of the side valley. Striae found on bedding surfaces of the Devonian Ohio black shale along the west side of the Scioto Valley

just north of the junction of the Indian Creek Valley appear fresh enough to be evidence for a Wisconsin ice tongue. Also the fact that remnants of Illinoian terrace gravels are present much higher along the northwest side of the valley would suggest that the varved sediments were deposited after the Illinoian outwash had been removed by Sangamon erosion. Soils on the upper silt vary from 40 to 60 in. deep but lack much development; best guess is that they are early Wisconsin. (Hyde [1921] believed these to be Illinoian varves since he considered that only a tongue of Illinoian ice could penetrate far enough down the Scioto Valley to block Indian Creek Valley.)

Significance of The Outwash Terraces

Pre-Illinoian stage.—The presence of at least two very old terrace remnants in the Hocking Valley at a higher elevation than Illinoian outwash, and on which a deeply weathered red soil is developed, may be evidence of pre-Illinoian outwash. These remnants add to evidence under study in the Cincinnati region of a Kansan (?) glacier reaching south-central and southwestern Ohio (Durrell, 1958). Although no glacial deposits definitely considered pre-Illinoian were found in the Scioto Valley, the water-laid sediments at elevations above the Illinoian terraces (fig. 3), thought to be deposits of the Teays River and Portsmouth River of Teays Stage, may in fact be pre-Illinoian glacial terrace deposits. The blocking of the Teays River system itself (Stout et al., 1943) is still considered to be due most probably to a pre-Illinoian glacier.

Illinoian stage.—Probably the most striking feature of the Illinoian terrace remnants in both the Hocking and Scioto Valleys is the presence of two distinct levels of outwash in both valleys, at least in their upper portions. Whether or not these two levels are actually present nearly all the way to the Ohio River in each valley is a matter for detailed leveling and discrimination. Leverett (1942) relates both levels to the Illinoian stage and suggests that an ice dam in the Cincinnati region provided a temporary ponding, resulting in the formation of the higher level; then, with its removal, the lower level was formed. The profiles (fig. 3), however, suggest that the two levels in each valley may merge to essentially one level near the Ohio River. This makes a Cincinnati ice dam unlikely as a controlling factor in the formation of two levels. All terrace levels were controlled by the load and hydraulics of the issuing streams at the ice edge.

A possible added interpretation is that the high and low levels in each valley were formed during separate ice advances of sub-stages of Illinoian time. The fact that each level heads in a different valley area is some argument that each Illinoian terrace level represents a different stage of advance of Illinoian ice. For example, the first high Illinoian outwash down the Hocking Valley headed two and one-half mi southeast of Lancaster and the second, lower Illinoian headed at the southeast edge of Lancaster, perhaps up Rush Creek and far west up Clear Creek. The first high Illinoian outwash down Scioto Valley headed just east of Chillicothe while the latter was farther east up Walnut Creek. Perhaps the strongest suggestion of two stages of the Illinoian is in the E ½ Sec. 21 and the W ½ Sec. 22 Springfield Township, Ross County (two mi east of Chillicothe between Lick Run and the Scioto Valleys) where Illinoian till actually lies over gravels contiguous with the higher Illinoian outwash; here the ice readvanced after the upper outwash was completed, but not as far as before.

Sangamon stage.—The deep, red brown to yellow brown soils developed on the Illinoian outwash terraces of both valleys are evidence of a long period of weathering and are considered typical of the soils developed on gravel in this region primarily during the Sangamon Interglacial Stage. That some of the development of soil continued into late- and post-Wisconsin time is evident in the cover or uniformly graded silt now recognized as loess. It extends onto older Wisconsin terraces as well, so this must be mostly Wisconsin loess and the present

soil on Illinoian terraces is redeveloped through the younger cover. The total profile is polygenetic. In the deeper silt soils, called Pike (Chillicothe), this is recognized in actual double profile. A Sangamon profile in loess is buried at four to six ft depth.

Another feature very evident is both valleys is the tremendous amount of Illinoian outwash that was removed prior to the deposition of the Wisconsin valley trains. This trenching of the Illinoian outwash is believed to have occurred during Sangamon time although the possibility exists of deepening by torrential waters from the advance of the earliest Wisconsin ice. There is no other evidence of enough Wisconsin meltwater to accomplish such a task in so short a time and much of the dissection is in side valleys heading scores of miles away from the site of Wisconsin meltwaters. The great dissection must be a measure of Sangamon time especially where lower Wisconsin terraces fill the cut.

Early Wisconsin substage.—The intermediate depths of Rush soil on the Lancaster terrace system and the scraps of higher terrace with intermediate soil profile (Williamsburg catena) in Paint Creek Valley all point to a post Sangamon glaciation prior to conventional Wisconsin substages. One might seek alternate explanations for the deeper soils on Wisconsin terrace levels, but neither texture nor lithology and certainly not climate indicate any reason. Variations in loess to a maximum of 30 in. were not found to make any significant difference here although an important variable elsewhere (Gooding, 1957). Carbonate content is similar in Lancaster and Carroll levels. On the other hand, Forsyth and La Rocque (1956) find evidence in superimposed drifts indicating an "earlier" Wisconsin; Goldthwait and Burns (1958) have interpreted buried soils and vegetation within the upper drift as a long mid-Wisconsin interval ending 18,000 to 25,000 yr ago (C^{14} dating). Thus, these terraces add to the accumulating evidence for a glacial phase of the Wisconsin Stage in Ohio prior to 30,000 yr ago.

The silt cover one and one-half to five ft deep on Illinoian, Lancaster, and Kingston terraces is interpreted as loess. Its mechanical composition shows excellent sorting since 60 to 80 percent of the grains falls between 0.002 and 0.05 mm diameter. (Courtesy of Soils Laboratory, Department of Agronomy, The Ohio State University.) Occasional pebbles, especially near the base, are interpreted as raised by frost, tree roots, or plowing; this is common in the Mississippi Valley. That this loess is rather thick on these Illinoian and higher Wisconsin terraces and missing on Carroll, Circleville, and Worthington terraces suggests that the principal dust storms were during the early Wisconsin before 30,000 yr ago and partly just after the development of the Kingston terrace. Although the loess has not been divided into stratigraphic units thus far, it is true that in any one valley loess on Illinoian terraces is deeper than that on early Wisconsin terraces. These in turn have more than Kingston terraces—but the capping on all is clearcut. Thus, we conclude that some aeolion deposit was begun in late Illinoian time, more was added after early Wisconsin, and the final foot or two were added just after the Kingston terrace but before Carroll or Circleville were completed.

Late Wisconsin substages.—The "late" (conventional) Wisconsin involves four main terrace substages. Two (Carroll and Circleville) may be simultaneous.

First and highest are the Kingston terraces, over 30 ft above all other Wisconsin levels north of Chillicothe. Since the northern-most remnant in the Scioto Valley is just north of the terminal moraine traced generally to the Cuba moraine (outer Wisconsin of Scioto Lobe) and since the accordant levels down Dry, Walnut and Paint Creeks come from the terminal moraine, it is held that this outwash formed during and just following the outer moraine formation, probably Cuba Moraine time (fig. 1). Elsewhere it is dated 17,000 to 18,000 yr ago (Burns and Goldthwait, 1958) but at present the most likely tie to type moraines in Illinois is Tazewell. The loess cover and relatively deep soil make it similar to Tazewell

terraces farther west. Even when this terrace building finished, ice still filled the Scioto Valley down to Chillicothe because there is not a matching level on the west side; near Kingston these were actually kame terraces and indeed there is a small kettle or two.

Second, and actually lowest in Hocking Valley, are the Carroll terraces. These tie by kettles and steepened gradient and kame terraces to the Carroll moraine ten mi within well known Wisconsin drift. That they have no loess cover suggests that they are later than the Kingston terrace, but there is loess on adjacent Wisconsin ground moraine through which Carroll outwashes passed. On the other hand, relatively deep Fox soil (48 in.) is more comparable to Kingston than to later Scioto terraces. Moraines are little help in settling this paradox of intervalley correlation, for the Carroll moraine is lost on highlands to its west. It seems by projection to predate the Marcy Moraine at Circleville which has been tentatively correlated with the Reesville Moraine farther west (fig. 1). The alternate and tempting hypothesis is that the Carroll and Marcy moraines are one in time and both produced simultaneous silt-free outwashes from Carroll and Circleville. But the Circleville outwash has a shallower soil profile and both are in uniform sand and gravel!

Third, then, is the Circleville terrace system. Prior to its deposition, readvancing ice stood along irregular moraine hills west of Kingston, and channels were cut out of the Kingston kame terrace at Kinnikinnick. As the ice retreated by undercutting of Scioto waters, the lower extensive valley fill called Circleville was built up from side to side across the whole valley. That accordant terraces extend only three mi up Deer Creek and not at all in Darby Creek indicates that there was ice covering these areas and the ice edge thus seems to correlate with Reesville Moraine. This in turn is tentatively correlated with the Bloomington Moraine of Illinois.

Fourth and last is the Worthington terrace system which while it converges toward older terraces downstream, is about 30 ft lower at Circleville and extends far up the Scioto and Olentangy Rivers to six mi north of Columbus. Kettles are present near Columbus. This is near to, but not at, the Powell moraine but, since accordant terraces reach up Darby Creek almost to the same moraine (yet not up Deer Creek), ice must have been about there. By latest tentative correlation this may be the time equivalent of the Minooka Moraine of outermost Cary Substage in Illinois.

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Radioisotopes—A New Tool for Industry. *Sidney Jefferson, B.Sc., A.C.G.I.* Philosophical Library Inc., New York 16, N. Y. 1958. viii+106 pages. $4.75.

This is an excellent presentation of the varied uses of radioisotopes in industry. Not only are the applications well described, but they are also well illustrated. The author has accomplished the feat of presenting the case for the use of radioisotopes in industry without innundating the reader with too technical explanations. The latter portion of the book is devoted to the atomic structure, the various kinds of radiations emitted by radioactive atoms, and a description of the devices used for detecting these emitted radiations. The contents of the book can be appreciated and understood by anyone with a limited background in chemistry and physics.

WILLARD C. MYSER

PLEISTOCENE MOLLUSCAN FAUNAS OF THE HUMBOLDT DEPOSIT, ROSS COUNTY, OHIO

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Location of Deposit

The Humboldt deposit is located 0.4 mi north of BM 798 at Humboldt, on Ohio Highway 41, Paint Township, Ross County, Ohio; Greenfield Quadrangle, southeast rectangle, at approximately 39° 16.87' north latitude and 83° 18.85' west longitude (fig. 1). It lies approximately 75 yd east of Ohio Highway 41 and is visible from the road only during the months when little or no foliage is present. The brightly colored gravel at the base of the section serves to distinguish this deposit since it is not exposed anywhere else in the immediate vicinity.

FIGURE 1. Index map, showing location of Humboldt deposit.

Methods of Investigation

The Humboldt deposit was sampled at two inch intervals. Each of the samples collected measured approximately 12 x 12 x 2 in. or 288 cu in. As the samples were collected they were numbered, placed in plastic bags, and sealed in order to maintain their moisture content.

In the laboratory, samples were placed in 2,000 ml beakers, covered with water, and allowed to stand from 24 to 48 hr. After soaking, the samples were washed through a series of sieves, separated into coarse, medium, fine, and very fine

fractions and allowed to dry. When dry, they were placed in containers and appropriately labeled.

The volume of shell material and matrix for each of the sections was quite large, in excess of three pints in some cases; their volume was reduced by quartering with a special device designed for that purpose. The unsorted material was passed through the quartering device and only a fraction of the original volume was retained to be sorted. The fraction retained depended upon the fossil content of the sample. Approximately 1,000 shells were selected at random from each of the fossiliferous sections.

Stratigraphy

The Humboldt deposit lies near the limit of continental glaciation in the low-lying Appalachian Plateau district of southern Ohio. It is an area that has been glaciated twice; both the Illinoian and Wisconsin glaciers considerably modified Buckskin Creek valley and filled it with a thick deposit of till and outwash.

The Humboldt section consists of nine units. The first three are composed of gravel, till, and sand and gravel, respectively, followed by the lacustrine deposits which compose units four through eight. Unit eight is overlain by a dark brown, blocky clay that is noncalcareous and contains numerous black shale fragments. The lake beds compose four ft of the total 32 ft in the measured section. They are typical in that they exhibit rapid lateral changes in lithology and considerable variation in thickness. They increase from four to ten ft in thickness when traced south and east of the measured section.

The extent of the Humboldt deposit is for the most part undetermined. It appears to be confined to the east valley wall; however, unfossiliferous clays and silts of freshwater origin are exposed on the west side of the valley and they may or may not be of comparable age. The fossiliferous lake beds were traced approximately 500 ft south and 100 ft east of the measured section and in both instances disappeared under thick deposits of colluvium.

The Humboldt area is characterized by steep slopes and local relief of the order of 500 ft. Both factors have greatly facilitated the large amounts of colluvial movement and slumping that have taken place in the valley. Because of this movement, exposures are limited, the best ones occurring in road cuts and near abandoned gravel pits.

The mollusk-bearing strata in the Humboldt deposit lie between units four and eight. The abundance of Mollusca increases upward; unit five is only slightly fossiliferous and unit six is more fossiliferous than unit five but considerably less so than unit seven (fig. 2).

Measured Section

Unit	Description	Thickness (inches)
9.	Clay, brown, blocky, noncalcareous, unfossiliferous	72
8.	Peat, black, clayey, blocky, noncalcareous, unfossiliferous	4
7.	Marl, reddish-brown to buff, calcareous, highly fossiliferous	17
6.	Silt, gray-blue, clayey, calcareous, fossiliferous	15
5.	Silt, buff, clayey, calcareous, slightly fossiliferous	6
4.	Silt, reddish-brown, clayey, calcareous, laminated, unfossiliferous; forms sharp contact with underlying sand and gravel	6
3.	Sand and gravel, buff to brown, calcareous, reddish-brown in places, contains dolomite ghosts, unfossiliferous	48
2.	Till, oxidized, brown, silty loam texture, calcareous, blocky structure not well-developed, unfossiliferous	96
1.	Gravel, coarse, calcareous, well-bedded, unfossiliferous	120+

Base of section not exposed.

Quantitative Distribution

The Mollusca of the Humboldt deposit are unevenly distributed from the quantitative standpoint. As may be expected, there is a definite correlation between the abundance of individuals and the lithology. In studying these specimens, the writer observed the presence of two major trends, from which there are several minor variations. The total species in the deposit number 18 (table 1); of these, ten occur more abundantly in the lower, more silty part of the section (collections ten through 18), seven in the upper, marly part (collections one through nine), and the remaining species is found in like numbers in both parts. *Amnicola leightoni*, *Gyraulus altissimus*, *Helisoma anceps striatum*, and

Unit Number	Collection Number	Total Individuals
8	1	0
7	2	5,905
	3	10,500
	4	21,000
	5	27,000
	6	58,000
	7	75,000
	8	120,000
	9	64,800
6	10	6,000
	11	2,273
	12	3,167
	13	2,133
	14	2,125
	15	1,000
	16	1,000
5	17	338
4	18	0

FIGURE 2. Quantitative distribution of Mollusca in the Humboldt deposit.

Valvata tricarinata are the most abundant species in this deposit; together, they form from 85 to 90 percent of the total fauna in each of the fossil-bearing strata. The writer assumes that the more significant species are those which form the largest proportion of the fauna although the lesser elements must not be overlooked; therefore, the above-mentioned species become the more significant forms. Three

of them, however, occur more abundantly in the upper part of the deposit, and as this has ecological significance, it will be discussed later.

Before examining the quantitative distribution in detail, a complete understanding of the relationship between the stratigraphic units and the collections is necessary. Collection 18 was taken from unit four, the reddish-brown, unfossiliferous silt; collection 17 was taken from unit five, the buff, slightly fossiliferous silt; collections ten through 16 were taken from unit six, the gray-blue, fossiliferous silt; collections two through nine were taken from unit seven, the reddish-brown to buff, fossiliferous marl; collection one was taken from unit eight, the black, unfossiliferous peat (fig. 2). In general, collections were taken at two-inch intervals; however, units four and five were so well indurated that another sampling technique was required and collections from these units were taken with chisel and hammer.

TABLE 1

Composition of fauna

Pelecypoda	Gastropoda
Pisidium compressum Prime	*Amnicola leightoni* F. C. Baker
Pisidium nitidum Jenyns	*Campeloma* sp., cf. *C. rufum* (Haldeman)
Pisidium nitidum pauperculum (Sterki)	*Ferrissia tarda* (Say)
Pisidium obtusale (Lamarck)	*Fossaria obrussa decampi* (Streng)
Pisidium variabile Prime	*Gyraulus altissimus* (F. C. Baker)
Sphaerium striatinum (Lamarck)	*Helisoma anceps striatum* (F. C. Baker)
Sphaerium sulcatum (Lamarck)	*Helisoma trivolvis* (Say)
	Menetus opercularis multilineatus (Vanatta)
	Physa gyrina (Say)
	Promenetus exacuous (Say)
	Valvata tricarinata (Say)

The following species occur more abundantly in the lower part of the deposit: *Valvata tricarinata*, *Campeloma* sp., cf. *C. rufum*, *Fossaria obrussa decampi*, *Pisidium compressum*, *P. nitidum*, *P. nitidum pauperculum*, *P. obtusale*, *P. variabile*, *Sphaerium striatinum*, and *S. sulcatum*.

The abundance of the majority of the species in the Humboldt deposit appears to be controlled by lithologic changes (fig. 3). The species *Valvata tricarinata* varies from 0 to 7.30 percent in collections one through nine; however, in collection ten there is a marked increase to 32.20 percent. Further, there is a noticeable decrease from collection 16 to collection 17 which also corresponds to a change in lithology. *Campeloma* sp., cf. *C. rufum* is one of the lesser elements of the Humboldt fauna. The majority of the specimens are concentrated in collections 12 through 16; however, this species never composes more than 0.90 percent of the total fauna. *Fossaria obrussa decampi* is distributed throughout the deposit. Its abundance does not appear to be much affected by lithologic changes. In general, it is more abundant in collections 11 and 12 and decreases gradually downward. All the species of *Pisidium* reach their greatest abundance in unit six. *P. nitidum*, *P. obtusale*, and *P. variabile* each compose less than one percent of the total fauna. *P. compressum* and *P. nitidum pauperculum* are the most abundant representatives of the genus, and they also conform rather well with changes in the lithology (fig. 4 and 6). Both species reach their greatest abundance in collections 13, 14, and 15. *Sphaerium striatinum* and *S. sulcatum* are confined entirely to unit six. They occur in collections 11 through 15 and reach their greatest abundance in collection 14; however, they never compose more than 0.50 percent of the total fauna.

The following species occur more abundantly in the upper part of the deposit: *Amnicola leightoni*, *Gyraulus altissimus*, *Helisoma anceps striatum*, *H. trivolvis*, *Physa gyrina*, *Menetus opercularis multilineatus*, and *Ferrissia tarda*. *Amnicola leightoni* is unique in that it is the only significant species to reach its greatest abundance in the upper part of unit seven (fig. 4). Also, little correlation exists between the abundance of this species and the lithology. Instead of decreasing from collection nine to collection ten, the species increases approximately ten percent; it then declines to 23.70 percent in collection 16. Again this species behaves differently from the remaining species and increases more than 40 percent from collection 16 to collection 17. This is best explained by considering the nature and the number of individuals present. The specimens from this collection

Coll. Number	Number of Individuals	Percent Total	10 20 30 40 50 60 70
1	0	0.00	
2	49	4.86	
3	51	5.00	
4	63	6.30	
5	51	5.10	
6	23	2.25	
7	14	1.39	
8	23	2.30	
9	73	7.30	
10	322	32.20	
11	364	36.40	
12	362	36.20	
13	366	34.69	
14	376	37.04	
15	356	34.90	
16	283	28.30	
17	37	10.95	
18	0	0.00	

FIGURE 3. Quantitative distribution of *Valvata tricarinata* in the Humboldt deposit.

are so fragmentary that identification is exceedingly difficult, and as only 338 individuals are present, the writer is inclined to doubt the validity of this sample. The change in lithology between collections nine and ten directly influences the abundance of *Gyraulus altissimus*, for there is an increase from 14.70 percent to 36.20 percent. On the other hand, the increase from collection 17 to collection 16 is negligible (fig. 5). *Helisoma anceps striatum*, like *Gyraulus altissimus*, reaches its greatest abundance in the lower part of unit seven, and from this point decreases,

with minor variations, in both directions (fig. 6). *Helisoma trivolvis* is confined entirely to unit seven. It occurs in collections seven, eight, and nine but never exceeds 0.30 percent of the total fauna. *Physa gyrina* is the most unevenly distributed species in the Humboldt deposit. Little or no correlation can be drawn between its distribution and the lithology. Although it is not one of the more significant species, it is certainly one of the more common, for it appears in each of the fossil-bearing strata. *Menetus opercularis multilineatus* is found only in collections two, three, and six. It attains its greatest abundance in collection two where it composes 0.60 percent of the total fauna. *Ferrissia tarda* occurs in both the lower and upper parts of the Humboldt deposit. However, 24 of the

Coll. Number	Number of Individuals	Percent Total
1	0	0.00
2	687	68.22
3	775	75.83
4	795	79.50
5	768	76.80
6	491	48.24
7	435	43.07
8	303	30.30
9	289	28.90
10	383	38.30
11	266	26.60
12	271	27.10
13	227	21.51
14	150	14.78
15	150	14.71
16	237	23.70
17	227	67.16
18	0	0.00

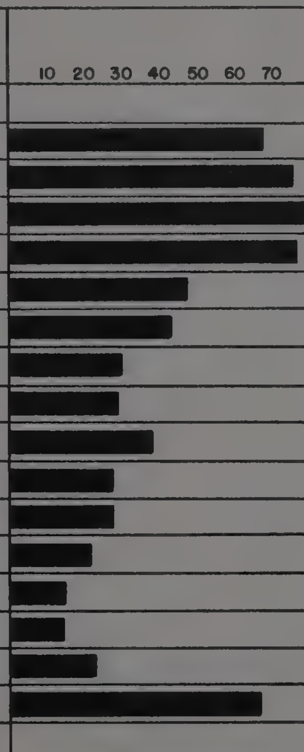

FIGURE 4. Quantitative distribution of *Amnicola leightoni* in the Humboldt deposit.

26 individuals present are found in collections two through six. *Promenetus exacuous* occurs in like numbers in both parts of the deposit; one specimen from collection 17, and one specimen from collection two.

A correlation exists not only between the lithology and the abundance of species, but also between the lithology and the total number of individuals in each of the collections. Figure 2 is an attempt to stress the preceding statement and to present another manner in which the Humboldt deposit may be compared with similarly studied deposits elsewhere. It also illustrates the influence of

changes in lithology on the abundance of Mollusca. There is an approximate threefold increase from collection 17 to collection 16, and over a tenfold increase from collection ten to collection nine, both of which correspond to changes in lithology.

Paleoecology

Methods of interpretation.—A preliminary examination of the list of species in table 1 establishes the freshwater environment of the Humboldt fauna. For the present it should be pointed out that the fauna is remarkable for the absence of

Coll. Number	Number of Individuals	Percent Total
1	0	0.00
2	175	17.38
3	120	11.74
4	102	10.20
5	123	12.30
6	313	30.69
7	302	29.90
8	310	31.00
9	362	36.20
10	147	14.70
11	175	17.50
12	129	12.90
13	130	12.32
14	134	13.20
15	118	11.57
16	92	9.20
17	25	7.40
18	0	0.00

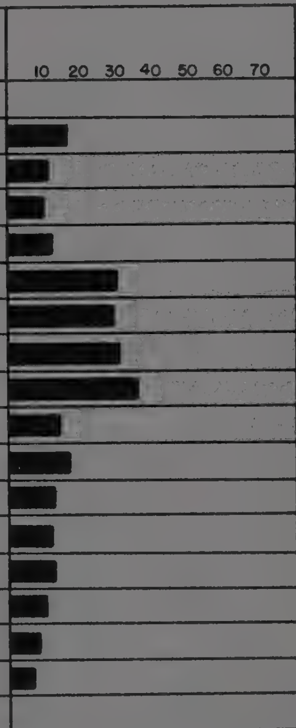

FIGURE 5. Quantitative distribution of *Gyraulus altissimus* in the Humboldt deposit.

land snails which are so often associated with Pleistocene lake deposits. This interesting fact is discussed later in detail.

Before attempting to reconstruct the environment in which the assemblage lived, a proper evaluation of the fauna must be made. *Amnicola leightoni*, *Gyraulus altissimus*, *Helisoma anceps striatum*, and *Valvata tricarinata* are the most significant species, i. e., those which form the largest proportions of the fauna. These species compose more than 20 percent of the fauna in one or more collections and are considered by the writer to be indigenous forms. On the other hand, the remaining species individually compose less than seven percent of the total fauna

in any one of the collections and for this reason they are considered to be transported forms, i. e., those which normally lived in a freshwater environment somewhat different from the environment indicated by the indigenous forms. In the following discussion, they are called nonindigenous forms.

The paleoecological information in the following paragraphs is summarized from the works of Baker (1910, 1911, 1916, 1918, and 1928), Berry (1943), La Rocque (1952), Mattox (1938), Moffett (1943), and Morrison (1932).

Indigenous species.—*Amnicola leightoni* is an extinct species; therefore, the only ecologic information available is inferred from that of its close relative,

Coll. Number	Number of Individuals	Percent Total	10 20 30 40 50 60 70
1	0	0.00	
2	76	7.55	
3	52	5.10	
4	26	2.60	
5	36	3.60	
6	147	14.41	
7	206	20.39	
8	308	30.80	
9	198	19.80	
10	39	3.90	
11	40	4.00	
12	34	3.40	
13	25	2.37	
14	32	3.15	
15	36	3.53	
16	20	2.00	
17	2	0.59	
18	0	0.00	

FIGURE 6. Quantitative distribution of *Helisoma anceps striatum* in the Humboldt deposit.

A. limosa (Say). *A. limosa* has been reported from a variety of habitats such as creeks, rivers, and fresh- and brackish-water lakes. It is capable of surviving in water from a few inches to ten ft in depth and appears to prefer bottom sediments characterized by a high percentage of sand. It is most abundant where there are thick beds of *Chara*, *Potamogeton*, *Vallisneria*, and *Elodea;* however, these plants are not used as food but harbor rich colonies of diatoms that the amnicolids eat. The species has also been observed feeding on slime, algae, and minute detritus of the top layer. Its outstanding enemies are fish. The pH for *A. limosa* is 7.95, and the fixed carbon dioxide ratio is 30.56 ppm.

A detailed examination of figure 4 indicates that the ecology of *A. leightoni* closely approximates that of *A. limosa.* The graph illustrates that *A. leightoni* was capable of surviving in a creek or river and in a lake; however, the conspicuous concentration of individuals in the marl (unit 7) suggests that they were better suited to the lake habitat for it was in this environment that they flourished and attained their greatest abundance.

Gyraulus altissimus is also an extinct species, except in localities far to the north and west of Ohio. It is possible to infer ecologic conditions from its close relative, *G. arcticus* ("Beck" Möller) which has been observed in small lakes with quiet water and abundant vegetation. La Rocque states that from its association with other species found both in Pleistocene and living faunas, it may be inferred that *G. altissimus* was a species of small lakes with a wide pH and fixed carbon dioxide range. The following figures for *G. arcticus* appear to support La Rocque's conclusions: pH 8.37, fixed carbon dioxide 25.75 ppm. In the Humboldt deposit there is a definite preference for the lake habitat and for conditions accompanying marl deposition.

Helisoma anceps striatum is an extinct form but from its associations with other species it may be inferred that it is predominantly a lake form, probably living in shallow water. The species has been recorded as common in Tomahawk Lake, Wisconsin, where it occurs on drifted logs and on sand and pebbles in shallow water. It also inhabits sheltered bays and exposed shores but there is a definite preference for the latter environment. Baker (1928) states that the form is an inhabitant of lakes that lived in the cold waters immediately after the retreat of the ice sheet. In the Humboldt deposit, quantitative distribution indicates that the lake habitat was preferred and that marl deposition permitted the form to flourish best.

Valvata tricarinata is a species of rivers, lakes, and permanent ponds, particularly where there is abundant vegetation. It is found on all varieties of bottoms and in all depths down to 18 ft. It is usually associated with the filamentous algae *Oedogonium* and *Cladophora*, and has been observed on *Vaucheria* upon which it was apparently feeding. It is preyed upon by numerous varieties of fish. Its pH range has been given as 7.16 to 8.37 and its fixed carbon dioxide ratio as 8.16 to 30.56 ppm. It reflects to a marked degree changes in the character of bottom sediments (fig. 3). It may be stated with some assurance that it prefers habitats where the bottom sediments are more or less firm and will enable the individuals to move freely about. In the Humboldt deposit they are much more numerous in the calcareous silts, again exhibiting their preference for compacted bottom sediments. With increasing marl deposition the species becomes less abundant.

Pisidium compressum is found in a variety of habitats, all of which have relatively firm bottoms. The typical form is confined principally to creeks and rivers, in water two to 6.3 m deep. It is a burrowing form and feeds on detritus and plankton. Species of *Pisidium* serve as food for many varieties of fish. The following figures have been given for this species: pH 7.0 to 8.37, fixed carbon dioxide 9.3 to 30.56 ppm.

Pisidium nitidum pauperculum has been collected in one and one-half to eight ft of water on sand and mud bottoms in Oneida Lake, New York. Baker (1928) lists the following specific habitats for Wisconsin: mud bottom, large lake, 1.5 m; sand and gravel bottom, 1.5 to 1.7 m; medium-sized lake, mud bottom, 1.2 to 3.4 m; sandy mud bottom, 1 m. The pH for this species is 7.0 to 8.0 and the fixed carbon dioxide 9.3 to 24.73 ppm. It burrows into the bottom sediments and feeds on detritus and plankton.

These two species of *Pisidium* are much more abundant than the remaining species of the genus in the deposit studied and reflect to a marked degree changes in lithology. The indigenous nature of these forms is indicated by their close

correlation with lithologic changes. During deposition of the silt in units four, five, and six, the bottom was probably more or less firm and compacted, enabling the small mollusks to burrow into the bottom where only their siphons remained uncovered. In the upper part of unit six there is an increasing amount of marl, and a corresponding decrease in numbers of *Pisidium*. In the lower part of unit seven the pelecypods decrease to less than one percent and then disappear entirely, probably because the marl bottom was too soft for shallow burrowing.

Nonindigenous species.—Little information is available concerning the ecology of *Campeloma rufum*. It appears to have lived in quiet, shallow water along the margins of the streams which flowed into the main body of water near Humboldt, and was probably transported into the deposit after death. It has been recorded from both lakes and streams in water one to six ft deep, from a variety of bottoms ranging from mud to sand, with or without vegetation

The small freshwater limpet *Ferrissia tarda* appears to be characteristic of cold, shallow, rapidly flowing streams with rocky bottoms. It has also been found on dead Naiad shells and debris. It seldom, if ever, strays from its preferred habitat, very rocky bottom, swift current, cold water six to 15 in. deep. It is evidently not an indigenous form in the Humboldt deposit. It probably lived in one or more of the streams draining into the lake.

Fossaria obrussa decampi has been collected along the swampy shores of a small bay in Tomahawk Lake, Wisconsin, in shallow water a few inches to a foot deep, on soft, sticky mud, with an abundance of algae. Its pH range is 7.42 to 7.7, fixed carbon dioxide 10.65 to 18.87 ppm. In the Humboldt area, it appears to have lived in marshy places along the margins of streams but possibly also along the margins of the lake where water was very shallow and the bottom muddy. Its scarcity may be an indication that such conditions were not common along the shores of the lake.

The widely distributed planorbid *Helisoma trivolvis* is always an inhabitant of quiet, even swampy and stagnant bodies of water, and usually occurs among vegetation. It is an obvious intruder in the Humboldt deposit and probably lived in the streams flowing into the lake. It has been collected from similar habitats, i. e., in protected pools on the margins of streams, filled with algae, and with abundant animal life.

Menetus opercularis multilineatus is a species for which no ecologic data are available. Its scarcity in the Humboldt deposits appears to indicate that it did not live in the lake but was transported, possibly from nearby streams.

Physa gyrina can exist in a variety of habitats, but it appears to be characteristic of slow-moving and stagnant bodies of water, usually on a mud bottom. It has also been found in overflows from large rivers and in small ponds behind river and lake beaches. Its pH is given as 7.1 to 8.37, fixed carbon dioxide 9.5 to 25.75 ppm. In the Humboldt deposit its numbers indicate that it is an intruder, probably washed in by streams.

Promenetus exacuous occurs in quiet, shallow water two to five ft deep on all varieties of bottoms; however, it is most abundant on sand and mud. It is found in habitats with thick vegetation and has been collected clinging to driftwood, dead leaves, and lily pads. It is also known to inhabit mud flats near the margins of small mountain streams of cold, clear water. Its pH range is given as 7.0 to 7.64, fixed carbon dioxide 9.3 to 22.5 ppm. It is associated with the algae *Cladophora fracta* and *Oedogonium*, and has been observed feeding on the dead leaves of *Typha angustifolia*. It is eaten by *Eupomotis gibbosus* (Linn.), the common Pumpkinseed. The presence of this small planorbid is best explained by assuming that it lived in quiet water on the mud flats near the margins of the streams which drained into the lake at Humboldt. It may have lived in the lake itself but if so, it did not flourish there.

Sphaerium striatinum is a burrowing form that lives in both streams and lakes.

It has been reported from swiftly flowing rivers but in shallow water near shore on a sandy mud bottom. In Oneida Lake, New York, it was found in two to three ft of water on a sandy bottom with occasional boulders, and in one to three ft of water on hard sand bottom. It feeds on detritus and plankton and is eaten by fish. Its scarcity probably indicates that it did not live in the lake itself but in streams flowing into it.

Little ecological information is available for *Sphaerium sulcatum*. It has been collected in Oneida Lake, New York, on mud in eight to 13 ft of water; in rivers in Wisconsin, on sand, mud, gravel, and mixed sand and gravel bottoms, in shallow water. It has a wide pH range, 6.9 to 8.37, and fixed carbon dioxide range, 9.3 to 25.75 ppm. Its scarcity also indicates that it lived in streams flowing into the lake.

Pisidium nitidum has been collected on a clay bottom in five ft of water, on a mud bottom in approximately 17 ft of water, and on a soft sand bottom in shallow water. Because of its scarcity, it is thought to have lived in streams flowing into the lake.

Pisidium obtusale has been collected on mud in eight and 11 ft in Oneida Lake, New York. No other ecological information seems to be available for this species. It is also thought to have lived in streams and not in the lake itself.

Pisidium variabile inhabits both rivers and lakes. It occurs frequently in water from one to 13 ft deep, burrowing in gravel, sand, clay, and mud, but is more abundant in mud where the water is four to 11 ft deep. The following figures have been given for this species: pH 5.72 to 8.37, fixed carbon dioxide 1.72 to 30.56 ppm. It feeds on detritus and plankton and is eaten by numerous varieties of fish. Its small numbers indicate that it lived in streams flowing into the lake and not in the lake itself.

Absence of land snails.—The majority of fossiliferous Pleistocene deposits are characterized by the presence of terrestrial gastropods in appreciable numbers, e. g., La Rocque (1952, p. 12) reports six species of land snails and 15 species of freshwater snails for the Orleton Mastodon site in Madison County, Ohio. Leonard (1953, p. 372) collected 15 species of land snails and only five species of aquatic gastropods in a Wisconsin loess at Cleveland, Ohio. Thornbury and Wayne (1957, pp. 5–27) give quantitative data for numerous deposits in Indiana, all of which contain large percentages of land snails. Other examples exist but are too numerous to be cited.

The Humboldt fauna is remarkable for the absence of land snails, a fact which serves to distinguish it from numerous other Pleistocene faunas. It is impossible to state that there is a total absence of land snails in the Humboldt deposit for this study is confined to one series of samples from one station. It may be stated, however, that if land snails inhabited the slopes some would have been preserved in the deposit. Also, if the slopes were populated there would probably be a concentration of land genera near the shoreline. Field evidence indicates, however, that the Humboldt deposit was sampled over 150 ft from shore. Evidently this distance is too great to expect the accumulation of large numbers of land snails. Nevertheless, it is noteworthy that no land snails were present in over 16,000 specimens examined.

Conclusions. The molluscan assemblage suggests a freshwater lake two to ten ft deep with abundant vegetation that served as food and cover for some species and harbored colonies of microscopic plants and animals that served as food for others. The pH varied from seven to eight and the fixed carbon dioxide ratio was approximately 24 ppm. A change in the pH and fixed carbon dioxide probably accompanied the change from silt deposition to marl deposition; however, there is no paleontological evidence to support this assumption.

The wide occurrence of laminated silts as far south as Valley School suggests that the lake occupied a large part of Buckskin Creek valley, approximately three mi in length and one-half mi wide.

Mollusca are known to have a variety of enemies, e. g., insects, birds, fish, and crustaceans. Their outstanding enemies are fish and the diet of some fish consists of 50 to 60 percent mollusks. It may be assumed that insects, birds, and crustaceans were present either in the lake or the immediate vicinity; however, there is direct evidence for the presence of fish. Naiades presuppose the presence of fish, and from the abundance of Naiades it may be inferred that numerous fish were present to feed on the mollusks.

The stratigraphy and paleoecological data furnish valuable information in reconstructing the history of the lake at Humboldt. The large, thick-shelled Naiades in the silts indicate moving water; however, these forms are replaced in the marl by the comparatively small, thin-shelled Naiad *Anodonta* sp., a quiet-water form. Therefore, the silts represent deposition during the early history of the lake when it was relatively shallow and there was active accumulation of glacial meltwater to provide sufficient current for the large, thick-shelled Naiades. The marl probably represents deposition in a somewhat deeper, more mature lake.

The high lime content of the sediments at Humboldt was probably derived from the extensive deposits of till and outwash in the valley. Little or no lime could have been derived from the bedrock for it is predominantly Ohio shale and has a low calcium carbonate content.

A modern parallel for the lake at Humboldt may be found in Sodon Lake, Oakland County, Michigan (Cain, Segadas-Vianna, and Bunt, 1950), although Sodon Lake appears to be in a later stage of development and has a more abundant fauna.

Age and Correlation

La Rocque and Forsyth (1957, p. 86) state:

> In Ohio, age determinations on the basis of molluscan faunules must be made with extreme caution and on a conditional basis for three reasons. In the first place, few assemblages have been studied in sufficient detail to serve for comparison with newly discovered faunules. Secondly, certain species, hitherto considered characteristic of a particular part of the Pleistocene, have later been recorded for younger or older sediments, which has led to modification of ideas on their stratigraphic significance. Thirdly, species of proven stratigraphic significance in other states, for example in Kansas, where so much has been accomplished by Leonard, may have a different value in Ohio because of different factors influencing the dispersal of Mollusca.

With these reservations in mind, all that can be done with the Humboldt fauna, from the standpoint of age determination, is to assemble all available information on the stratigraphic range of the species in Ohio and elsewhere and to draw tentative conclusions from this information. Despite these restricting conditions it is still possible to arrive at a fairly definite age for the Humboldt fauna.

The stratigraphic range of each of the Mollusca, so far as known at present, is shown in table 2. It should be pointed out that it contains three species, possibly more, that are not now living in Ohio. Two of these, *Amnicola leightoni* and *Gyraulus altissimus*, are entirely absent from living assemblages in Ohio. The other is represented in Ohio by the typical form but its variety, *Helisoma anceps striatum*, has not been reported from living faunas in the state.

To postulate an age older than Illinoian for this deposit seems unreasonable. Twelve species in the deposit are not represented in Yarmouthian deposits and fifteen have not been reported in deposits of Kansan age.

Leonard (1950, p. 41) gives the following stratigraphic ranges for some fresh-water Mollusca collected from Yarmouthian deposits in the midcontinent region of the United States; lower Pliocene to Recent, *Helisoma anceps* (Menke) and *Physa anatina* Lea; Aftonian to Recent, *Fossaria parva* (Lea); restricted to Yarmouthian, *Gyraulus labiatus* Leonard, *Menetus pearlettei* Leonard, and *Gyraulus pattersoni* Baker; Yarmouthian to Recent, *Pisidium compressum* Prime, *Promenetus umbilicatellus* (Cockerell), *Gyraulus similaris* (Baker), *Valvata tricarinata* (Say),

Helisoma cf. *H. wisconsinense* (Winslow), *Amnicola limosa parva* Lea, *Helisoma trivolvis* (Say), *Sphaerium* sp., *Physa elliptica* Lea, *Valvata lewisi* Currier, and *Ferrissia parallela* (Haldeman). All of the genera mentioned above are also found in the Humboldt fauna; however, the large majority of the species are incongruous. On the basis of this information an age determination older than Illinoian is discarded.

TABLE 2

Stratigraphic range of identified species of the Humboldt fauna

Species	PLIO*	NE	AF	KA	YA	IL	SA	WIS	LIV
Pisidium compressum Prime	N	N	N	B	B	B	B	B	B
Pisidium nitidum Jenyns	N	N	N	N	A	C	C	H	D
Pisidium nitidum pauperculum (Sterki)	N	N	N	N	A	C	C	H	D
Pisidium obtusale (Lamarck)	N	N	N	N	N	N	N	H	D
Pisidium variabile Prime	N	N	N	N	A	C	C	H	D
Sphaerium striatinum (Lamarck)	N	N	N	N	N	N	N	H	D
Sphaerium sulcatum (Lamarck)	N	N	N	N	N	N	N	E	D
Valvata tricarinata (Say)	N	N	N	B	B	B	B	B	B
Campeloma sp., cf. *C. rufum* (Haldeman)	N	N	N	N	N	N	D?	H	D
Amnicola leightoni F. C. Baker	N	N	N	N	N	N	N	E	N
Fossaria obrussa decampi (Streng)	N	N	N	N	N	N	N	E	D
Helisoma anceps striatum (F. C. Baker)	N	N	N	N	N	N	N	E	N
Helisoma trivolvis (Say)	N	N	N	B	B	B	B	B	B
Menetus opercularis multilineatus (Vanatta)	N	N	N	N	N	N	N	H	G
Promenetus exacuous (Say)	N	N	N	N	N	N	N	E	D
Gyraulus altissimus (F. C. Baker)	N	N	N	N	N	N	F?	E	F
Ferrissia tarda (Say)	N	N	N	N	N	N	N	H	D
Physa gyrina Say	N	N	N	N	N	N	N	H	D

*Explanation of symbols

PLIO	Pliocene	SA	Sangamon	D	La Rocque (1953)
NE	Nebraskan	WIS	Wisconsin	E	Baker (1920)
AF	Aftonian	LIV	Living	F	Russell (1934)
KA	Kansan	A	Leonard (1950)	G	Vanatta (1895)
YA	Yarmouth	B	Frye and Leonard (1952)	H	Humboldt deposit only
IL	Illinoian	C	By inference from the existence of an older record.	N	Not recorded

The position of the deposit between two tills suggests the possibility of a Sangamon or Illinoian age. Ten of the 18 species of the Humboldt fauna have not been recorded for Sangamon deposits and 12 have not been recorded for Illinoian deposits. If an age older than Wisconsin is assumed then the stratigraphic range of ten species must be extended to corroborate this assumption. This is unlikely but not impossible, however, for the range of other species has been extended in the past. Nevertheless, the fact remains that, at present, these ten species have not been found in deposits older than Wisconsin in Illinois, Indiana, Ohio, and Kansas. Also, geologic evidence supports a Wisconsin age much more strongly than a Sangamon or an Illinoian one. Therefore it must be concluded that the Humboldt fauna is Wisconsin in age.

In order to avoid an age determination based entirely on the Mollusca, the glacial history of south-central Ohio and Buckskin Creek valley was studied in some detail. A complete understanding of the stratigraphy in the valley is pre-

requisite to an interpretation of the glacial history. Therefore, a composite stratigraphic section is presented below. Information gathered from an exposure several hundred feet south of the measured section and from a jeep-mounted power auger is incorporated in the section.

Unit	Description	Thickness (feet)
9.	Till, silty and clayey, oxidized brown, calcareous	15
8.	Till, silty and clayey, unoxidized blue-gray, calcareous	17
7.	Clay, smooth and somewhat plastic, generally blue-gray, entirely non-calcareous, contains rich zones of Ohio black shale	24
6.	Peat, containing abundant crushed Mollusca	⅓–2
5.	Marl, clayey, very fossiliferous	3–5
4.	Marl and clay, laminated in places, slightly fossiliferous in upper portion	1–6
3.	Sand and gravel, reddish-brown in places, calcareous	0–5
2.	Till, oxidized brown, silty, calcareous	5–8
1.	Gravel, coarse, stratified	10 +

This gravel appears to be the same as that exposed in an abandoned gravel pit 0.3 mi south of the measured section where it persists to a higher elevation, has in it a well-developed Sangamon soil, and is overlain by a calcareous till that is apparently continuous with the upper till of this section.

The gravel exposed in the abandoned gravel pit and containing the Sangamon soil is undoubtedly of Illinoian age. The till overlying the gravel has a depth of leaching of 50 to 60 in. and has been mapped by Mr. James H. Petro of the Ohio Division of Lands and Soil as "early" Wisconsin, with the meaning suggested by Goldthwait and Forsyth and explained by La Rocque and Forsyth (1957, p. 81). This till appears to be continuous with the uppermost till in the composite section. Also, pebble counts in the basal gravel of the Humboldt section and in the gravel that contains the well-developed Sangamon profile strongly indicate that they are one and the same. If this is true, then the basal gravel in the measured section must also be Illinoian in age and its surface must have been eroded after the soil profile developed, probably by the first advance of the "early" Wisconsin ice. Therefore, it must be concluded that the Humboldt deposit is "early" Wisconsin in age.

Correlation of the Humboldt deposit is difficult for only one deposit has been assigned an "early" Wisconsin age in Ohio, the Sidney Cut, Shelby County (La Rocque and Forsyth, 1957). Although the faunas apparently are of the same age the environments suggested by the Mollusca are very different. The genera represented in the Sidney Cut, with the exception of *Fossaria*, are land pulmonate gastropods whereas the Humboldt fauna is entirely freshwater. Since little can be accomplished by correlation, perhaps comparisons with faunas of known age will serve to substantiate the age determined for the Humboldt fauna.

Baker (1920) has studied approximately 20,000 shells collected by M. M. Leighton from the south end of Rush Lake, Logan County, Ohio. The deposit lies within the limit of "late" Wisconsin drift and is considered to be post-Wisconsin in age. The list of species was revised by La Rocque (1952, p. 22). The Rush Lake fauna closely approximates that of the Humboldt deposit but its affinities are much closer to living faunas than those of Humboldt.

La Rocque (1952) has studied the Mollusca from two layers in the Orleton Mastodon site, Madison County, Ohio. The lacustrine deposits rest on till that has been dated as Cary ("late" Wisconsin) by Goldthwait (1952, pp. 5–9). The list of species (La Rocque, 1952, p. 12) is of interest for comparison with the Humboldt fauna because it is one of the few which includes quantitative data. The differences between the Orleton and the Humboldt lists may well be attributed to the difference in age, the smaller size of the Orleton lake, the longer period of

development of the Humboldt lake, and the greater distance of Orleton lake from a major drainage system.

The age of the Humboldt fauna can definitely be stated as Wisconsin, and perhaps just as definitely "early" Wisconsin, for three reasons. First, a Wisconsin age determination is indicated by the presence of ten species that have not, at present, been recorded for deposits older than Wisconsin. Secondly, an "early" Wisconsin age is suggested by the incongruity of the Humboldt fauna with faunas that are "late" Wisconsin or post-Wisconsin in age. Thirdly, the fact that the Humboldt deposit overlies a gravel that has in it a well-developed Sangamon soil and underlies a till that has been mapped as "early" Wisconsin by soil scientists proves rather conclusively that it is "early" Wisconsin in age.

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SOME SOIL FACTORS AFFECTING THE DISTRIBUTION OF BEECH IN A CENTRAL OHIO FOREST[1]

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INTRODUCTION

A primary objective in plant ecology is understanding the relationships between the environment and the processes of the plant, and hence better understanding the development of its structure and form and its communal relationships. One approach to this problem lies in measuring the variations in some pertinent environmental factors and then evaluating their effects on the processes and structures of the plant.

During the summer of 1953 a study was conducted on radial growth of beech, *Fagus grandifolia* Ehrh., as related to soil moisture (Fritts, 1956a). A dial-gauge dendrometer was used to measure radial changes on three beech trees and these changes were related to soil moisture measurements in the three sites.

Each of the three trees had different regimes of radial growth which appeared to be associated with differences in soil moisture regimes. The tree on the best drained site had a gradual but early cessation of growth as soil moisture was reduced to wilting percent. The tree in the most poorly drained site had an even earlier cessation which was much more abrupt than that of the tree on the drier site. This cessation occurred at a time when the upper soil levels were drying rapidly. The tree in an area of intermediate drainage, with less competition from surrounding trees, had more available soil moisture for a longer period, and its growth continued later into the season.

The present study was undertaken to examine in detail these three soil environments grading from a moderately well-drained site, where the beech-maple association is dominant, to a very poorly drained site where beech is only an occasional associate of the swamp forest community. Other environmental and tree growth measurements were made concurrently (Fritts, 1956b) and these data are presented in a separate paper (Fritts, 1958).

DESCRIPTION OF AREA

The forest in which this study was conducted, called Blacklick Woods, is a relatively undisturbed beech-maple and swamp forest tract located ten mi east of Columbus and one mi south-southwest of Reynoldsburg, Ohio (Fritts, 1956a). The area is on the gently undulating Wisconsin till plain, with elevations varying from 870 to 895 ft. A study area of 2.72 acres was selected to include one of the better drained sites in the forest as well as a poorly drained area where beech grows only along the edge of the depressions.

The soils of the area investigated have developed on moderately calcareous coarse clay loam or loam till and include three soil types, all members of the Alexandria Catena. Cardington silt loam, which is a moderately well-drained Gray-brown Podzolic soil, occurs on the low ridges and knolls. (The definitions of the soil drainage classes are defined in Soil Survey Manual [Soil Survey Staff, 1951].) Bennington silt loam, an imperfectly drained Gray-brown Podzolic soil,

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is on the lower very gentle slopes between the low ridges and the depressions. The third soil type, the Marengo silty clay loam, is a very poorly drained Humic gley soil of the depressions.

In the analyses of the vegetation within the area, which has a total range in elevation of six ft, every tree over one in. dbh was mapped as to its location and relative elevation of the site (Fritts, 1956b). The total area, the number, and the basal area of each species included in the lower two-foot, the middle two-foot, and the upper two-foot contour intervals were calculated and the data plotted (fig. 1).

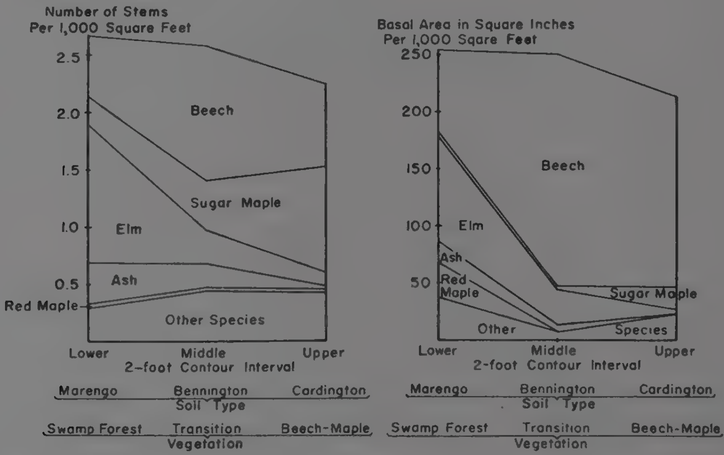


FIGURE 1. The numbers and basal area of stems over 1 in. dbh per 1,000 ft² on the three sites, as determined from mapping the trees and establishing 1-ft contour lines. Each soil type and its forest community was found, as indicated above, to lie within a 2-ft contour interval in the local study area. The relative proportion of each species is represented by proportionate areas for each site. The top line is equivalent to the total of all stems.

FIGURE 2. The early spring aspect of the swamp forest association on the Marengo silty clay loam (left) and the beech-sugar maple association on the Cardington silt loam (right).

Marengo silty clay loam is the prevalent soil in the lower two-foot interval. Bennington silt loam and Cardington silt loam are the dominant soils in the middle and upper two-foot intervals respectively. On the Marengo soil of the very poorly drained site, American elm (*Ulmus americana* L.), white ash (*Fraxinus americana* L.), and red maple (*Acer rubrum* L.) are the dominant species (fig. 2,

left). Associated with them are: *Quercus bicolor* Willd, *Carpinus caroliniana* Walt, *Carya cordiformis* (Wang.) L. Koch, and *Tilia americana* L. Beech becomes established near the borders where the drainage is slightly better, but it is less important than elm. On the somewhat better drained Bennington soils, beech reaches its best development, small sugar maple trees (*Acer saccharum* Marsh.) become more abundant and elm becomes less important. In the more open areas of this site, the understory of spicebush (*Lindera benzoin* (L.) Blume) is more dense than anywhere else in the study area. Where better drainage prevails, as in the Cardington soil of the low knolls and ridges, beech and sugar maple are the dominant species (fig. 2, right). Also occurring on these better drained sites are *Celtis occidentalis* L., *Prunus Serotina* Ehrh., *Cornus florida* L., and *Asimina triloba* (L.) Dunal.

METHODS

A detailed profile description of each of the soil types was made in a pit excavated within approximately ten ft of beech trees. The soil colors were determined in the moist state; the color terminology and Munsell notations used follow the definitions given in the Soil Survey Manual (Soil Survey Staff, 1951).

A bulk sample was taken of each of the soil horizons in each pit for laboratory analyses which included mechanical analyses and the determination of organic matter, pH, exchange acidity, and exchangeable calcium, magnesium, and potassium. The pipette method of Steele and Bradfield (1934) was used in the mechanical analyses with sodium hexametaphosphate as a dispersing agent. Organic matter and pH were determined by the method of Peech et al. (1947). Exchangeable calcium, magnesium and potassium were extracted with neutral normal ammonium acetate (Peech et al., 1947) and the extract analyzed on a Beckman Model DU flame photometer. Exchange acidity was determined with the method of Mehlich (1945), using a barium chloride solution buffered with triethanolamine.

Eight core samples were also taken when possible from each horizon at the three sites. Considerable difficulty was encountered in taking core samples of the C horizons of the Cardington and Bennington soils because of the appreciable content of rock fragments. On six of these core samples the following physical measurements were made: (1) bulk density and (2) the content of moisture expressed on volume basis at (a) saturation, (b) ten cm tension, (c) 60 cm tension, (d) one-third atm pressure, and (e) 15 atm pressure. The values obtained through these measurements were used to calculate total porosity, aeration porosity, and the available moisture as shown below:

$$\text{Bulk density} = \frac{\text{Weight of soil (oven dried) in gm}}{\text{Volume of soil in cm}^3}$$

$$\text{Total porosity} = \frac{\text{Moisture content in soil at saturation}}{\text{Volume of soil}}$$

$$\text{Aeration porosity} = \frac{\text{Moisture content at saturation} - \text{moisture content at 60 cm tension}}{\text{Volume of soil}}$$

$$\text{Available moisture} = \frac{\text{Moisture content at } \tfrac{1}{3} \text{ atm pressure} - \text{moisture content at 15 atm pressure}}{\text{Volume of soil}}$$

Wilting percent was determined on the remaining two core samples of each horizon by the following method: Oats were planted immediately after sampling and the samples were left in a controlled temperature and light room until the plants were four in. high, when watering was discontinued. When the majority

of the plants became permanently wilted, i.e., would not regain turgidity when placed in a nearly saturated atmosphere overnight, the soil was weighed, oven-dried, and percent volume moisture was ascertained.

The tree root distribution was mapped in the field for a one-ft wide section of each of the three soil profiles (fig. 3). The Cardington root distribution was mapped in June, 1954; Bennington in August, 1955; Marengo in August, 1954.

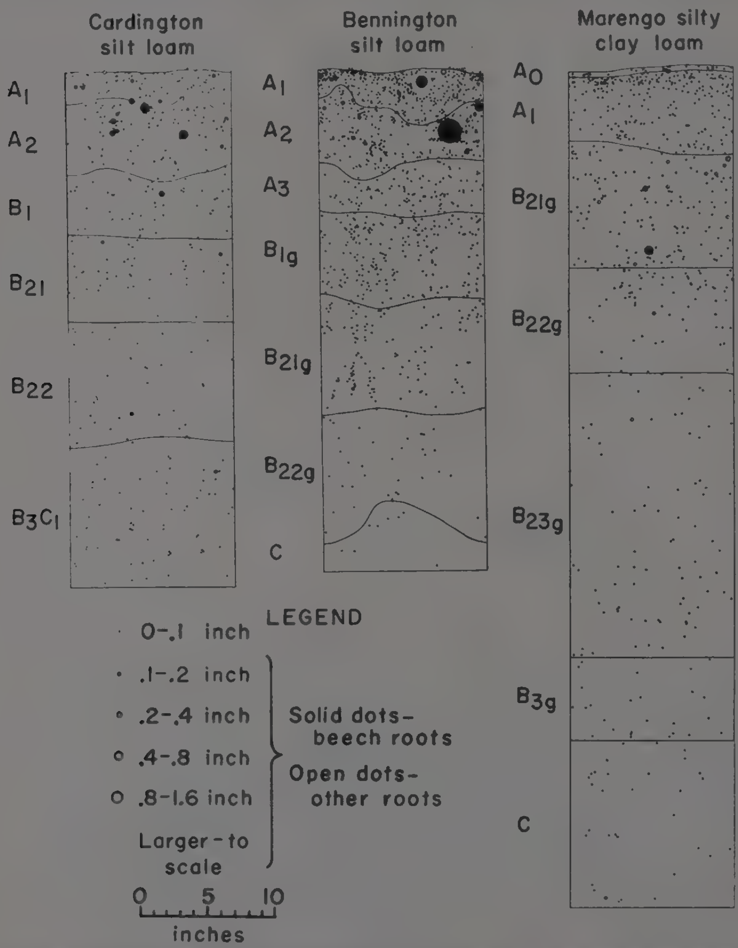


FIGURE 3. Map showing root size and distribution along a 1-ft transverse section of each soil profile. Beech roots greater than 0.1 in. diameter are indicated by solid dots and those of other species are indicated by open dots. Boundaries of the several soil horizons are indicated.

The density of all roots for each horizon was ascertained from the mapped section. In addition, all roots larger than 0.1 in. in diameter were identified and mapped as beech or nonbeech. This provided a means of estimating the extent of the more permanent root system of beech.

Field measurements of soil moisture were made by means of fiberglas-gypsum blocks (Youker and Dreibelbis, 1951). Six units were placed at each of the three depths—six, 12, and 24 in.—in undisturbed soil near the beech trees on each soil type. Resistance readings were made at intervals throughout the growing seasons of 1954 and 1955 by means of a Colman soil moisture meter. For calibration purposes, soil moisture samples were also taken at each of the three depths with a King-tube sampler near each unit at various times during the season and the moisture content was determined gravimetrically. This method for measuring soil moisture is discussed in the Southern Forest Experiment Station Occasional Papers (1953, 1954) and is described in more detail by Fritts (1956b).

Soil temperatures were measured at six, 12, 24, and 36-in. depths in each soil type by means of homemade thermistors and read with the Colman meter.

RESULTS

Morphology of Soils

The characteristics of each of the three soils as observed in the field are reviewed in the detailed descriptions and in the discussion following.

1. *Cardington silt loam.*—This soil was described and sampled in a pit located between two canopy beech trees on a 3 percent slope of a gently sloping knoll.

Depth and Horizon	*Soil Profile Description*
2–0″ A_0	Leaf litter.
0–2½″ A_1	Very dark gray silt loam (10YR3/1 4/1); moderately developed, medium and coarse, granular structure.
2½–7″ A_2	Light yellowish brown coarse silty clay loam (10YR6/4); very weakly developed, subangular blocky to almost massive structure.
7–12″ B_1	Yellowish brown silty clay loam (10YR5/6), faintly mottled with light yellowish brown (10YR6/4), moderately developed, fine and medium, subangular structure; occasional sandstone pebbles present.
12–18″ B_{21}	Yellowish brown clay (10YR5/8), with prominent, large, brownish yellow (10YR6/8) and light brownish gray (10YR6/2) mottling; structure consists of moderately developed, fine prismatic forms that break up into strong, medium, subangular blocky units; some pebbles of shale, sandstone, and chert present.
18–27″ B_{22}	Yellowish brown clay (10YR5/6), with prominent, grayish brown mottling (10YR5/2 4/2); moderately developed, medium, angular and subangular blocky structure; pebbles of leached limestone and of black shale fragments common.
27–38″ C_1	Yellowish brown calcareous clay loam (10YR5/4), faintly mottled with brownish yellow (10YR6/6) and intermingled with prominent light brownish gray splotches and coatings of calcareous material (10YR6/2); weakly developed, coarse, prismatic structure; firm; numerous fragments of limestone and black shale present.
38–54″ C_2	Yellowish brown coarse clay loam till (10YR5/4 5/6), with few faint brownish yellow mottles (10YR6/6) and light brownish gray (10YR6/2) calcareous coatings; firm. Numerous pebbles and fragments of limestone and black shale present.

2. *Bennington silt loam.*—The pit where this soil was sampled and described is located eleven and one-half ft from a beech tree, on a footslope occupying an

intermediate position between the knoll where Cardington silt loam was sampled and the shallow depressed area of Marengo silty clay loam soil. This footslope had a gradient of between one and two percent.

Depth and Horizon	*Soil Profile Description*
1–0″ A_0	Partially decomposed leaf litter.
0–2″ A_1	Very dark gray silt loam (10YR3/1 4/1); moderately developed very coarse granular structure.
2–6″ A_2	Light brownish gray silt loam (2.5Y6/2); weakly to moderately very fine subangular structure.
6–10″ A_3	Gray coarse silty clay loam (10YR6/1) with common medium distinct yellowish brown mottles (10YR5/6); moderately developed fine subangular blocky structure.
10–16″ B_{1g}	Light brownish gray silty clay (2.5Y6/2) with many medium distinct yellowish brown mottles. The light brownish gray color more prominent on the structural unit surfaces; moderately developed fine subangular blocky structure.
16–24″ B_{21g}	Silty clay. Gray clayey coatings (2.5Y5/) with the interiors distinctly mottled with an intermingling of gray (2.5Y5/) and yellowish brown (10YR5/8); weakly developed medium prismatic structure breaking up into moderately developed angular and subangular blocky units.
24–30″ B_{22g}	Silty clay. Distinctly mottled color with an intermingling of yellowish brown (10YR5/8) and gray (10YR5/1) and (2.5Y5/); weakly developed coarse prismatic structure breaking up into weakly developed fine angular and subangular blocky units; some clayey coatings along structural unit surfaces.
30–44″ C_1	Brown calcareous clay loam till (10YR5/3 4/2) with gray coating (2.5Y6/) on prism faces and some yellowish brown mottling (10YR5/8); coarse weakly developed prismatic structure; very firm in place. Fragments of limestone black shale and yellowish brown limestone constitute about 20 percent of volume.
44–56″ C_2	Dark brown calcareous coarse clay loam (10YR4/3) with occasional gray coatings (2.5Y6/) along vertical faces; massive with some vertical partings; very firm in place. Fragments of limestone, sandstone and black shale and some igneous pebbles make up 15 to 30 percent of volume.
56–63″ C_3	Dark brown calcareous loam (10YR4/3) with rock fragments similar to those of C_2. Firm in place.

3. *Marengo silty clay loam.*—This soil occupies a shallow depression about 75 yd wide. The site sampled and described is located near the edge of this depression and nine ft from a beech tree.

Depth and Horizon	*Soil Profile Description*
0–7″ A_1	Very dark gray silty clay loam (10YR3/1); strongly developed fine and medium granular structure.
7–15″ B_{21g}	Gray clay (2.5Y5/) with fine faint brownish yellow mottling (10YR 6/6); moderately to strongly developed fine and medium angular blocky structure.

15–22″ B_{22g}	Clay, distinctly mottled with an intermingling of gray (2.5Y6/) and olive yellow (2.5Y6/8), with the gray occurring mainly on the structural unit surfaces; weakly to moderately developed fine angular blocky structure; some small soft black concretions present.
22–42″ B_{23g}	Clay, prominently mottled with an intermingling of brownish yellow (10YR6/8), light brownish gray (10YR6/2) and gray (5Y5/1); the gray colors mainly on structural unit surfaces; structure consists of weakly developed prismatic forms that break up into weakly to moderately developed medium size angular blocky units.
42–48″ B_{3g}	Silty clay loam mottled with an intermingling of brownish yellow (10YR6/8) and light gray (2.5Y10YR6/1) with the latter being more common on the structural unit surfaces; weakly developed medium prismatic structure breaking up into weakly developed subangular units.
48–72″ C_1	Yellowish brown calcareous coarse clay loam (10YR5/4) distinctly mottled with gray (10YR5/1) on the structural unit surfaces. Weakly developed fine subangular blocky structure.
72–78″ C_2	Pale brown calcareous coarse clay loam till (10YR2.5Y6/3) faintly mottled with grayish brown (10YR5/2).

It is evident from the preceding descriptions that the three soils differ appreciably in colors of the various horizons. The yellowish brown hues are much more prevalent in the upper part of the profile of the Cardington soil. This is indicative of relatively better aeration. Gray colors, or the intermingling (mottling) of gray, yellow, and yellowish brown colors, are associated more with reduced aeration conditions such as are obtained when the soils are saturated for appreciable periods of time during the warmer season. The latter colors are more common throughout the subsoils in the Bennington and are especially extensive and well developed in the Marengo soil.

A characteristic distribution of structure may be noted in these soils. The A horizons in all three of the soils have a moderately to strongly developed granular structure. It is fine or very fine weakly developed subangular blocky in the A_2 horizons of the Cardington and Bennington soils, merging into coarser and strongly or moderately developed subangular or angular blocky in the B horizons. This better developed structure extends to a greater depth in the Cardington soil. In the case of the Marengo, a soil which lacks the A_2 or A_3 horizons, the granular and thicker A is underlain by horizons having more angular structure, though the units are generally fine or very fine and tend to be weakly developed. In general the angular or subangular units in the B horizons of the three soils tend to be arranged in weakly developed prismatic forms, the latter breaking up easily into the subangular or angular units mentioned. There is an increase in size and a decrease in degree of development of the structural units with depths, so that in the C horizons the structure is weakly developed coarse prismatic or massive. Also, the C horizons are rather dense and very firm, suggesting a lower degree of permeability to air and water, as well as to root penetration (fig. 3).

Chemical Properties

The data obtained on the chemical properties of the soils are shown in table 1. It is evident that, outside of the A_1, the upper horizons of the Cardington and Bennington soils are very strongly acid with base saturation as low as 19 and 16 percent, respectively, in the A_2 horizons. There is a decrease in acidity and an increase in base saturation in these soils with depth in the lower B horizons, the profiles becoming calcareous in the C. Marengo silty clay loam is medium or

strongly acid in the upper horizons only. The base saturation, with the lowest value being 49 percent, is appreciably higher in the upper part of the profile than in the other two soils.

Except for the B_{1g} and B_{21g} of the Bennington, calcium is the predominant exchangeable basic cation in the three soils, followed by magnesium and then potassium. The quantities of exchangeable bases in these soils differ appreciably, being relatively low in Cardington and Bennington in comparison to values obtained for the Marengo.

TABLE 1

Chemical properties of Cardington, Bennington, and Marengo Soils in the study area, Blacklick Woods

Horizon	Depth (in in.)	Organic matter %	Nitrogen %	pH	Base saturation %	Exchange acidity ME/100gm	Exchangeable bases ME/100gm Ca	Mg	K
				Cardington silt loam					
A_1	0 – 2½	7.3	.32	5.5	51	10.2	8.6	1.6	.36
A_2	2½– 7	1.9	.10	4.5	19	10.2	2.0	.3	.14
B_1	7 –12	1.0	.08	4.7	31	11.8	3.5	1.7	.18
B_{21}	12 –18	.9	.07	4.8	47	12.2	6.0	4.3	.29
B_{22}	18 –27	1.2	.09	7.3	90	2.2	13.0	7.1	.26
B_3C_1	27 +			calcareous					
				Bennington silt loam					
A_1	0 – 2	5.7	.33	5.8	44	13 2	8.0	2.1	.40
A_2	2 – 6	1.7	.11	5.2	16	11.1	1.3	.6	.16
A_3	6 –10	.4	.05	4.9	17	11.7	1.1	1.2	.10
B_{1g}	10 –16	.6	.06	5.0	33	14.8	3.3	3.7	.19
B_{21g}	16 –24	.6	.07	5.1	50	12.2	5.8	6.2	.26
B_{22g}	24 –30	.8	.07	6.2	83	4.0	10.8	8.3	.26
C	30 +			calcareous					
				Marengo silty clay loam					
A_1	0 – 7	8.3	.41	5.3	49	16.6	11.5	3.8	.53
B_{21g}	7 –15	1.3	—	5.0	57	10.7	9.3	4.5	.29
B_{22g}	15 –22	0.9	.06	5.3	70	6.8	10.0	5.5	.28
B_{23g}	22 –42	0.9	—	6.0	78	4.7	10.0	6.2	.25
B_{3g}	42 –48	1.4	.07	6.8	87	2.4	10.5	5.7	.18
C	48 +			calcareous					

There are some differences in the distribution and content of organic matter in the three profiles. Both the Cardington and the Bennington soils have a surface layer (A horizon) about two in. thick with a relatively high organic matter content—7.3 and 5.7 percent, respectively. There is a sharp decrease in these values in the underlying horizons. In the case of the Marengo soil, the A horizon has an organic matter content of 8.3 percent and is seven in. thick. Thus, to a depth of about six or seven in., the Marengo soil contains appreciably more organic matter than do the other two soils.

The C horizons in these soils are calcareous. Though the data on the carbonate equivalent content have not been included in table 1, the values range between 13.3 to 23.0 percents. The depth of the calcareous C horizon is greater in the Marengo, being 48 in., while it is only 27 and 30 in., respectively, in the Cardington and Bennington soils.

Physical Properties

A number of physical properties of these soils which may contribute to the local distribution of beech were measured at each horizon. Measured or derived values were obtained for mechanical composition, bulk density, total and aeration porosity, moisture retention capacities at different degrees of extraction, and wilting percent. In addition, the seasonal changes in soil temperature and moisture content at various depths were determined, and an analysis of root concentration was made from the maps of each profile. Results are presented in tables 2, 3, and 4, and in figures 4 through 8. Each of the physical properties is considered separately in the following discussion.

TABLE 2

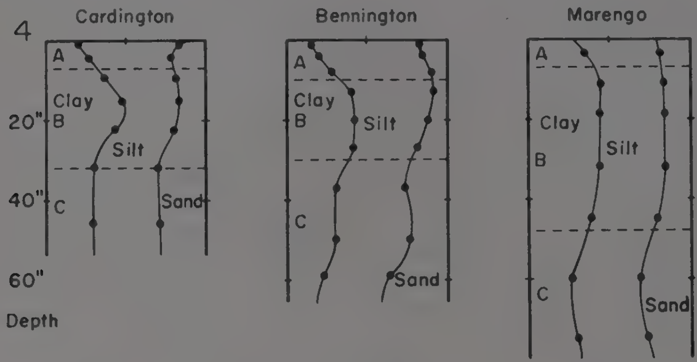
Root distribution and some physical properties of Cardington, Bennington, and Marengo soils in the study area, Blacklick Woods

Horizon	Depth (in in.)	Sand %	Silt %	Clay <0.002 mm diameter %	Bulk density	Total porosity %	Aeration porosity %	"Available" water, in. water per in. of soil	Roots per in^2.
				Cardington silt loam					
A_1	0 – 2½	16.9	62.3	20.8	——	—	——	——	3.74
A_2	2½– 7	20.4	51.4	28.2	1.34	55	18.9	.237	1.69
B_1	7 –12	17.9	45.7	36.4	1.52	45	12.3	.117	.94
B_{21}	12 –18	15.7	36.1	48.2	1.52	48	8.5	.123	.67
B_{22}	18 –27	19.8	36.4	43.8	1.61	42	7.1	——	.35
B_3C_1	27 –38	29.8	40.3	29.9	——	—	——	——	.55
C_2	38 –54	29.0	41.7	29.3	——	—	——	——	——
				Bennington silt loam					
A_1	0 – 2	17.6	66.6	15.8	——	—	——	——	9.32
A_2	2 – 6	15.6	64.2	20.2	1.33	46	11.7	.125	4.77
A_3	6 –10	10.0	61.3	28.7	1.44	44	11.8	——	2.57
B_{1g}	10 –16	8.7	51.1	40.2	1.39	46	9.1	.134	2.79
B_{21g}	16 –24	11.8	45.9	42.3	1.47	45	5.3	.083	1.39
B_{22g}	24 –30	18.3	40.3	41.4	1.55	42	4.7	.080	.40
C_1	30 –44	26.2	42.5	31.3	——	—	——	——	.21
C_2	44 –56	23.7	45.7	30.6	——	—	——	——	——
C_3	56 –63	36.8	40.4	22.8	——	—	——	——	——
				Marengo silty clay loam					
A_1	0 – 7	18.2	46.4	35.4	1.13	58	10.9	.250	3.58
B_{21g}	7 –15	15.7	39.0	45.3	1.40	47	6.5	.145	1.41
B_{22g}	15 –22	15.3	40.5	44.2	1.53	43	5.0	.114	.80
B_{23g}	22 –42	15.4	40.0	44.6	1.58	42	5.2	.096	.34
B_{3g}	42 –48	20.0	40.9	39.1	——	—	——	——	.36
C_1	48 –72	31.5	41.5	27.0	1.72	37	3.4	.064	.23
C_2	72 –78	26.5	43.4	30.1	——	—	——	——	——

1. *Mechanical composition* (*soil texture*).—The percents of sand, silt, and clay in each horizon are included in table 2 and their relative distribution with depth is shown in figure 4. It is evident that both the Cardington and Bennington are characterized by a comparatively low clay content in the A horizons, having minimum values of 20.8 and 15.8 percent, respectively. There is a pronounced increase in this fraction in the B horizons of these two soils, with maximum values

being 48.2 and 42.3 percent. This contrast in clay content of the A and the B is less marked in the Marengo, though there is some increase in this fraction in the B horizon. A value of 35.4 percent was obtained for the A_1 while a maximum content of 45.3 percent was found in the B_{21g}. The clay content is fairly uniform in the C horizons, which constitute the till parent material of these soils. Values obtained range from 22.8 to 31.3 percent, but most of these samples contain around 30 percent clay.

4



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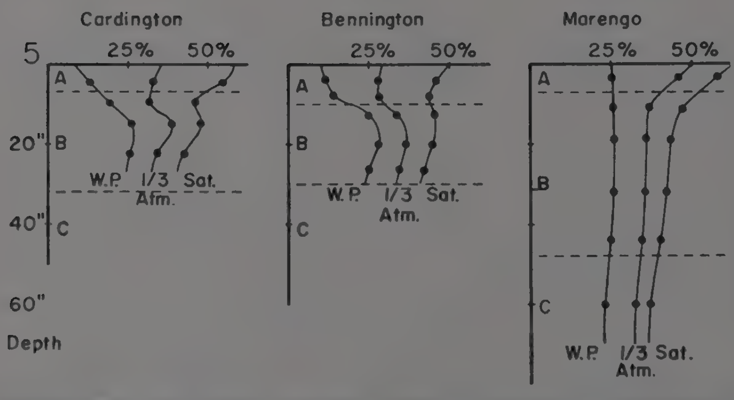


FIGURE 4 (top). The relative proportions of sand, silt, and clay in the profiles of the Cardington, Bennington, and Marengo soils. The area between lines at a given depth represents the percent of each soil fraction. A, B, and C are the three master soil horizons.

FIGURE 5 (bottom). Distribution of percent volume of moisture retained at saturation, at one-third atm, and at wilting percent at various depths in the profiles of Cardington, Bennington, and Marengo soils. A, B, and C are the three master soil horizons.

One of the soils, the Bennington, shows a relatively higher content of the silt portion in the upper part of the profile. The silt content exceeds 60 percent in the A_1, A_2, and A_3 horizons, and 50 percent in the B_1 of this soil. This is appreciably higher than the values obtained for the Cardington soil at comparable depths.

2. *Bulk density.*—Data in table 2 indicate that the bulk densities are relatively low in the A_1 horizons of the three soils, with values of around one or slightly

greater. They increase progressively with depth, reaching a value slightly above 1.5 in the B_2 horizons, and around 1.7 in the C. Only one measurement is available on the A_1 horizon—that of the Marengo, for which an average value of 1.13 for six core samples was obtained. Core samples of this horizon in the Cardington and the Bennington soils were not taken because of the sampling difficulties encountered due to the shallowness of that horizon and the profusion of horizontal roots near the surface. The organic matter content of this horizon in these two soils is nearly as high as that of the Marengo, and hence it is estimated that their bulk densities would have values comparable to that of the Marengo. No serious difficulties were encountered in the sampling of the B horizons of the three soils; so a larger number of measurements are available; but in the C horizons of the Cardington and Bennington, the presence of rock fragments precluded the taking of good samples. For this reason only one set of C horizon bulk density measurements was made, that of the Marengo, for which an average value of 1.72 was obtained. Judging from bulk density measurements made on the C horizons of other comparable soils in central Ohio, the above value can be accepted for the other two soils.

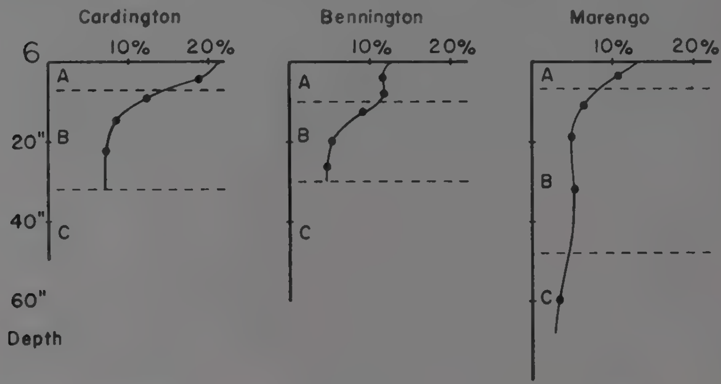
3. *Soil moisture retention capacities.*—The quantities of moisture retained by the three soils at various depths and at different degrees of extraction or saturation are shown in figure 5. Wilting percent, which was determined with the use of oat seedlings, shows the greatest variation with depth, especially in the Cardington and Bennington soils. The quantities of moisture retained by these two soils at wilting percent are respectively 12.7 and 14.0 percent of soil volume in the A_2 horizons, reaching maxima of 26.6 and 28.1 percent in the B_2. In this respect the wilting percent tends to parallel the content of clay at different depths in the profiles. A more uniform distribution with depth of wilting percent values may be noted in the Marengo soil. In this case, the moisture retained at wilting percent varies from 25.5 to 26.8 percent in the A and the B horizons. A lower value of 21.3 percent was obtained in the C.

The moisture retained by a soil after it has been wetted and then subjected to one-third atm of air pressure, is generally considered to be a measure of its capacity to hold moisture when saturated and allowed to drain under field conditions. The values obtained for this moisture retention capacity at various depths in the three soils are shown graphically in figure 5. In the A horizons of the Cardington and Bennington, the one-third atm moisture values are 32.5 and 27.7 percent soil volume and increase to maxima of 38.6 and 36.8 percent in the B horizons. In the case of the Marengo soil, this moisture value is 46.8 percent in the A, decreasing to 35.9 in the B_2, and to 32.5 percent in the C.

The difference between the quantity of moisture retained at 15 atm and one-third atm pressure is indicative of the quantity of moisture a soil can retain that can be used by the plant. It is referred to as "available" water, and in table 2 is expressed as the inches of available water that one in. of soil can hold. (The pressure membrane measurement of 15 atm is used here instead of wilting percent, since the former was made on the same cores as were used for one-third atm determination.) The upper horizons exhibit the largest capacities. Values of 0.237, 0.125, and 0.250 were obtained for the A_1 or A_2 horizons of Cardington, Bennington, and Marengo soils. These values decline with depth in the subsoils (with the exception of a slight increase in the B_{1g} of the Bennington), the lowest value of 0.080 occurring in the B_{22g} horizon of the Bennington. Even lower quantities apparently could be expected in the C horizons, since a value of only 0.064 was obtained at this depth in the Marengo soil. An additional means for expressing graphically the available water holding capacities of the three soils is provided in figure 5. The area between the wilting percent and the one-third atm curves is a measure of this capacity with depth in each soil.

Quantity of water retained by the soil when saturated was also measured.

Since saturation implies the filling of the larger pores with water, the increase in moisture content at saturation over the content at one-third atm will be dependent on the magnitude of aeration porosity. Examination of figure 5 reveals the highest saturation values in the A horizons where aeration porosity is greatest. Somewhat lower quantities were found in the B and the lowest in C.



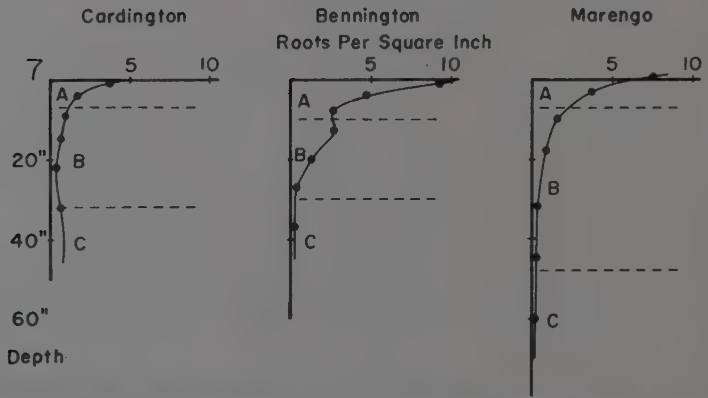


FIGURE 6 (top). Percent aeration porosity for each horizon in the Cardington, Bennington, and Marengo soils. A, B, and C are the three master horizons.

FIGURE 7 (bottom). Root density per horizon in the Cardington, Bennington, and Marengo soils. A, B, and C are the three master soil horizons.

4. *Total and aeration porosity.* Total porosity (i.e., the percent by volume of the pore space in the soil) is inversely related to the bulk density. As shown in table 2, it is greatest in the A horizon and least in the C of the three soils investigated. A value of 58 percent was obtained for the A_1 horizon of the Marengo and comparable values could be expected in the A_1 horizon of the other two soils. A value of 37 percent was obtained for the C horizon of the Marengo, which is indicative of the decline in aeration porosity with increasing bulk density. The total porosity values of the B horizons of these soils are of intermediate magnitude, ranging from 42 to 48 percent.

There are more marked differences in relative extent of the aeration porosity at different depths in these soils. The values reported in table 2 and shown in figure 6 represent the percent by volume of the space occupied by the larger pores in the soil. These values are an index of the quantity of the larger pore spaces through which air and water may move more readily and hence may be especially significant in tree growth through the effect on growth and distribution of roots. The aeration porosity values are relatively high in the A horizons, ranging from 10.9 in the Marengo, up to 18.9 percent in the Cardington. They are considerably lower in the B horizons, especially in the B_{22g} of the Bennington and the Marengo soils where values of 4.7 and 5.0 percent, respectively, were obtained. This decrease in aeration porosity in the subsoil is not as great in the Cardington soil,

TABLE 3

Average monthly temperatures in degrees F, May through October of 1954 and 1955, at the 6, 12, 24 and 36-in. depths in Cardington, Bennington, and Marengo soils, Blacklick Woods

Depth	May		June		July		August		September		October	
(in in.)	1954	1955	1954	1955	1954	1955	1954	1955	1954	1955	1954	1955
						Cardington silt loam						
6	51.3	56.3	60.4	58.8	63.5	63.5	65.7	64.8	62.0	—	60.0	—
12	52.3	56.3	60.8	58.3	62.8	63.0	63.7	64.8	61.7	—	60.3	—
24	52.2	54.3	58.4	58.0	61.0	60.0	63.2	63.2	61.7	—	61.3	—
36	50.8	52.5	55.8	55.5	59.2	57.5	62.0	61.8	61.0	—	60.7	—
						Bennington silt loam						
6	—	57.0	62.2	60.3	64.5	63.3	65.7	64.8	61.3	—	58.7	—
12	—	56.0	61.0	58.8	64.3	62.8	65.8	64.8	62.7	—	60.0	—
24	—	53.8	59.4	56.0	62.3	59.5	64.2	62.8	61.7	—	59.3	—
36	—	52.8	56.4	55.0	60.3	57.8	61.2	61.8	61.3	—	60.7	—
						Marengo silty clay loam						
6	—	57.5	—	61.3	66.7	65.0	66.5	65.6	60.7	—	58.5	—
12	—	58.5	—	60.3	66.0	65.3	67.0	66.8	62.3	—	61.0	—
24	—	56.0	—	59.3	63.8	61.3	65.2	64.0	62.0	—	61.0	—
36	—	54.8	—	58.0	61.8	60.0	63.2	63.6	61.3	—	60.5	—

the values being 8.5 and 7.1 for the B_{21} and the B_{22} horizons. Very low values appear to be common to the C horizons, as indicated by the 3.4 percent obtained for this horizon in the Marengo soil. This strongly suggests a very low permeability to air and water in this part of the three profiles.

It should be pointed out that in the A_2 horizon of the Bennington the available water, as well as the total and aeration porosity, is markedly lower than in the A_2 of the Cardington and at comparable depths in the Marengo. Apparently the higher silt content of the Bennington has a pronounced effect on the water relations.

5. *Soil temperatures by seasons.*—Soil temperature data averaged by months for the measured portions of the years 1954 and 1955 are presented in table 3. In this forest during the spring and early season, the Marengo soils appear to be warmest and the Cardington coolest to a depth of at least 36 in. In the autumn, the Marengo cools most rapidly and the Cardington least rapidly. However, temperature differences among the three soils at the same depths and at the same time were seldom greater than 2 or 3°F.

6. *Root numbers and distribution.*—The average root densities per horizon shown in table 2 and in figure 7 indicate the effects of the several soil factors on root development. The better drained and aerated Cardington soil, in comparison with the Bennington, has a lower density of roots in the upper soil levels; but the root numbers as a whole do not decrease as markedly with depth in the B and C horizons. The lower root density in the Cardington may be due partly to the fact that the roots were mapped two months earlier in the season (June), and partly due to less available moisture in this soil during the greater part of the growing season. Below the B, the density of roots actually increases in the lighter textured C horizon. This is apparent not only in the number of roots but also in their increased size and branching. A tree in this type of soil, therefore, would be likely to have a deep root system.

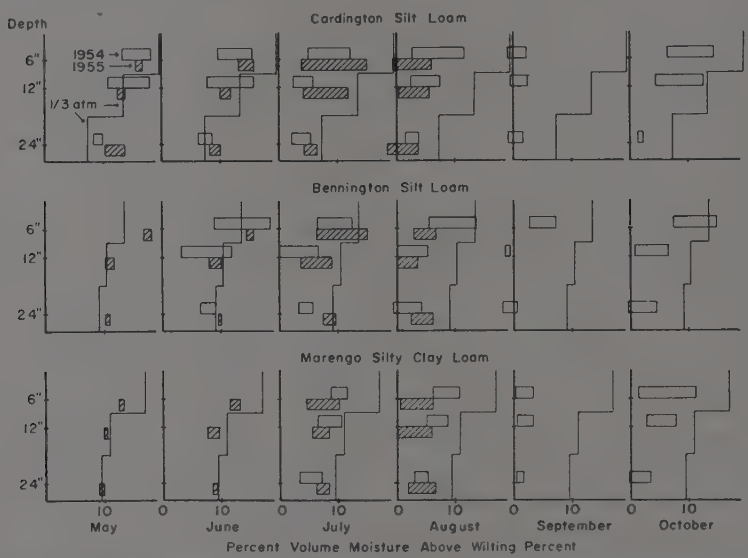


FIGURE 8. The observed monthly range of percent volume soil moisture above wilting percent at the six, 12, and 24-in. depths for the Cardington, Bennington, and Marengo soils during 1954 and 1955. The steplike line represents one-third atm tension minus wilting percent for each of the three depths.

In the Bennington soil there is a high concentration of roots in the A_1 horizon; they occur in appreciable numbers down into the B_{1g} as well, but decrease sharply below this depth. The greater concentration of roots appears to be confined to the horizons having higher porosity values and a relatively high silt content. The roots evidently branch profusely in the A_1 and upper B_{1g} where aeration is relatively favorable, but in the lower B horizon they become less and less extensive where the clay content becomes higher and aeration lower. Few roots appear to penetrate below this layer. A tree in this soil type would have a more concentrated root system, restricted largely to the A and upper B horizons.

The Marengo soil has an even more marked decrease in root numbers with depth. Here aeration drops off rapidly with depth, especially during the spring and early summer when the soil is saturated. As a consequence, the roots are largely restricted to the upper soil horizons.

An even more striking contrast of root penetration into these soils may be noted in the distribution patterns with depth of the larger roots (i.e., roots of 0.1 in. diameter or greater). From table 4 it is evident that these larger roots of beech are relatively extensive and deep in the Cardington; that they are restricted mostly to the A horizons in the Bennington; and that in the Marengo they are relatively shallow and less frequent.

TABLE 4

Number of roots larger than 0.1 in. diameter of beech and of other species by horizons exposed in one ft transverse section in Cardington, Bennington, and Marengo soils, Blacklick Woods

Horizon	Depth (in in.)	Roots, diameter >0.1 in. Beech	Others
	Cardington silt loam		
A_1	0 – 2½	5	1
A_2	2½ – 7	8	0
B_1	7 –12	1	0
B_{21}	12 –18	2	0
B_{22}	18 –27	1	0
B_3C_1	27 –38	1	0
	Bennington silt loam		
A_1	0 – 2	5	3
A_2	2 – 6	5	0
A_3	6 –10	0	0
B_{1g}	10 –16	0	0
B_{21g}	16 –24	0	0
B_{22g}	24 –30	0	0
C	30 –44	0	0
	Marengo silty clay loam		
A_1	0 – 7	0	2
B_{21g}	7 –15	2	10
B_{22g}	15 –22	0	1
B_{23g}	22 –42	0	1
B_{3g}	42 –48	0	0
C	48 –72	0	0

7. *Seasonal soil moisture changes.*—Measurements of soil moisture content at the six, 12, and 24-in. depths were made periodically during the period of May through October in 1954 and 1955. A summary of the data obtained during these two years is presented graphically for each soil in a series of monthly charts in figure 8. Each monthly chart shows the observed range in fluctuations of soil moisture readings above the wilting percent value at each depth.

All the soils were wet (i.e., soil moisture content exceeded one-third atm values) during the early part of the season. Ponded conditions generally prevail on the Marengo soil. There may be some doubt about the moisture readings obtained for the Marengo soil during the month of May. At several times when measurements were being taken on this soil, there was a puddled condition which suggested that moisture content exceeded one-third atm values; yet this was not indicated by the resistance readings obtained on the moisture blocks. The error here is probably due to the lack of calibration points while the soil was in this ponded condition. Accurate samplings at this time could not be made.

The moisture in the A horizon of the Cardington first began to decrease in May, although a saturated layer remained above the clay maximum in the B horizon well into June. It is evident that during this time water entering the soil exceeded that which was removed by roots or by percolation. Therefore, considerable internal lateral movement must have occurred down the slope into the upper horizons of the lower soils, augmenting their saturated condition. This was evidenced by seepage from the sides of the holes or pits which were open at that time. In June, as transpiration and root growth increased, water was removed from the soil more rapidly and the moisture in all soils began to decline. During the rest of the season, soil moisture variations at the recorded depths were the resultant of the moisture changes through additions by rain, and removal by the roots. In the moderately well-drained Cardington soil, where the root concentration was less dense and the roots were more evenly distributed throughout the profile, the soil moisture was reduced proportionally at all depths. The greatest moisture changes occurred in the upper horizon, the fluctuations corresponding with the rainy and the rainless periods.

The Bennington soil had a marked contrast between the moisture regimes at the three depths. At the six-in. depth, the measured soil moisture was never reduced to wilting percent during the two years studied, while at the 12-in. depth soil moisture dropped earlier and more rapidly than in any other site at the equivalent depth. At the 24-in. depth the soil moisture regime was similar to that of equivalent depths in the other two soils.

Several factors may account for the contrast in the Bennington regime. Two soil moisture stations on the Bennington were located on the margin of an opening in the canopy made by a windthrow. The dense understory of spicebush, a partially decomposed stump, and the eccentric crowns of neighboring trees indicated that the open condition had existed for a number of years. Because of the opening, a large portion of rainfall reached the soil surface and high moisture levels were maintained in the A horizon. In addition, the total water-holding capacity (see available water, table 2) is lower in the A of the Bennington than in the corresponding horizons in the other two soils; with a rain, this lower water-holding capacity would result in a rapid percolation of water, since field capacity would be quickly reached. The opening in the canopy and the resulting higher rainfall reaching the soil at the two stations, and the more rapid percolation in the Bennington resulted in a more frequent replenishing of the soil moisture at the six-in. depth than occurred in the other soils.

However, even in the Bennington, moisture from summer rains seldom reached the 12-in. level. The moisture accumulated in this soil during the winter and spring is readily depleted by the high number of roots in the upper B horizon and wilting percent may first occur here as it did in July, 1954 (fig. 8). The tight B_{22g} horizon prevents large numbers of roots from reaching the 24-in. depth and the moisture regime shows less variation.

In the poorly drained Marengo site the soil moisture regimes at both the six and 12-in. depths were more alike, and the moisture, while below field capacity, did not become very low until August or September. At the 24-in. depth, where roots were sparse, there was much less variation; wilting percent was not attained until still later in the season, when aeration was sufficient to allow deeper root penetration, thus causing greater water loss from this lower depth.

DISCUSSION

It is apparent from these data that the soil environment changes appreciably in this forest throughout the range of beech. It appears to have a great influence upon the root distribution. The structural and aeration porosity differences in the soil profiles favor deeper root penetration in the Cardington, while the beech roots are more restricted to and concentrated in the shallower depths of the

Bennington, and are most restricted in the Marengo. These differences are due largely to the higher early-season moisture and poorer aeration in the more poorly drained sites.

In all three soils, the roots below the A horizons are largely confined to the outer surfaces of the soil structural units. In the high clay B_2 horizons, where the structural units become larger, there is less potential total area for root growth and consequently less root penetration. In the Cardington, although this B_2 horizon reaches a high maximum concentration of clay, it is not as deep; it has a higher aeration porosity, and the structure is somewhat more strongly developed than in the other two soil types. These conditions evidently allow the roots to penetrate the layer and reach the lighter textured C horizon where the roots increase in density and size. In the Bennington, fewer beech roots can penetrate the B horizon, and in the Marengo, where the areation of the B is even lower, still fewer beech roots occur.

In the Marengo, the high base status and the high organic content might be favorable to a high root growth in the A_0 and A_1, when, in mid and late summer, aeration is not limiting; but at times when the aeration is poor, the slightly higher temperatures may cause respiration of the roots to be somewhat greater and make aeration a more potent limiting factor.

Furthermore, a root system should be considered as a dynamic rather than a static system, where many of the deeper roots in poorly drained soils may die back to a greater or lesser extent in the spring, depending upon the soil conditions and the characteristics of that particular species. Absence of large beech roots in the Marengo soil seems to substantiate this. As the soils progressively dry and growing conditions become more favorable, the roots grow into lower areas of higher moisture content. During an average summer when temperatures are not extreme and transpiration is not excessive, the root systems of beech can extend with sufficient rapidity in all three sites to supply water for the entire growing season; but in a summer such as 1952 (Fritts, 1956a), when the soil moisture is high during early season but decreases rapidly during July when air temperatures are high, the root system of the beech on the Marengo soil may not grow rapidly enough into the moist layers to maintain sufficient water absorption. This would result in a water deficit in the tree with a consequent early and abrupt cessation of growth, coinciding with the beginning of hot, dry weather.

If the drought of 1952 had been even more severe, the beech trees in this poorly drained site may have died. Braun (1936) mentions such cases occurring on Illinoian till in southwestern Ohio. She says, ". . . the shallowness of the root systems of beech in wet and poorly aerated soil resulted in high mortality of this tree in depressions in the 1930 drought." Shanks (1942) also states that the root systems in the swamp forest of Trumbull County, Ohio, are very superficial and that in this swampy region the beeches frequently have dead tops.

It is very likely that an extremely wet spring and summer would also be unfavorable for growth of beech on these poorly drained soils, due to prolonged periods of poor aeration. Because of conditions unfavorable to the growth of beech, other species which are more tolerant to these conditions of poor aeration and which would have a more extensive root system, would grow better in this soil type. Beech trees on the better drained sites, however, would have better soil aeration and a deeper root system; soil moisture would not become as limiting in a drought year, nor aeration as limiting in an excessively wet year. Beech therefore reaches its best development on these better drained soils.

The roots of the less shade-tolerant swamp forest species, such as soft maple, white ash, and American elm, evidently can better withstand the periods of poor aeration occurring in the Marengo soil; therefore, they are the dominants in these poorly drained sites in which beech does not grow well. Sugar maple, the major competitor of beech, is probably even more adversely affected than beech by the

poor aeration in the spring; therefore, it occurs as a dominant only on the better drained soil, such as the Cardington, in this forest. This shade-tolerant competitor reduces the area available to beech and causes it to decrease in importance in this better drained soil.

As can be seen from figure 1, both the total number of all tree stems and total basal area decrease with better drainage, especially from the Bennington to the Cardington soil. Lutz (1932) mentions the fact that the number of plant individuals decreases from poor to good sites and he attributes this to the more rapid growth and early expression of dominance of trees on better sites. However, such an explanation does not account for the decrease in basal area per unit area on the better drained sites of the study area. This reduction in both basal area and number more likely results from the lower available soil moisture and better aeration of the higher soils, which occurs consistently year after year. These conditions may allow individual trees to have large root systems and to grow to a large size, but they limit the number of individuals and total basal area that can occupy a given soil volume. In the Bennington, and more so along the margin of the Marengo, the supply of available soil moisture is frequently higher; thus, trees can grow in greater abundance per unit area. However, these trees on the less well-drained sites are more subject to climatic extremes and may be set back, if not killed, by exceedingly wet or dry years. It seems more likely that the occurrence of these extreme conditions prevents trees on the more poorly drained sites from reaching the large size obtained by those on the better drained soils.

Hence, it would appear that beech in central Ohio may have the most consistently favorable soil environment from year to year on the moderately well-drained Cardington silt loam because here it develops a deep root system. However, because of low available soil moisture and the presence of sugar maple, beech is not as abundant as it is on the imperfectly drained Bennington silt loam. In this less well-drained soil, sugar maple does poorly and soil moisture is frequently higher, allowing beech to become more abundant, although here it has a shallower root system. In the poorly drained outer border area of the Marengo silty clay loam, the beech reaches its lower limits. Here where soil moisture is often high, aeration is limiting and roots are restricted to the upper soil levels. When drought does occur, these shallow-rooted beech are most severly affected.

According to definitions of the several soil drainage classes given in the Soil Survey Manual, each class refers to, among other properties, the frequency and duration of periods of saturation in the various parts of the soil profile. For example, the Cardington silt loam is classed as being moderately well-drained, and according to this classification, the water is removed from the soil somewhat slowly, and the profile is wet for small but significant periods of time. The Bennington silt loam is classed as being imperfectly, or somewhat poorly, drained. Here the water, by definition, should be removed from the soil slowly enough to keep it wet for significant periods, but not all of the time. The Marengo is described as being very poorly drained, and here the water, by definition, should be removed from this soil so slowly that a water-saturated condition persists at or on the surface the greater part of the time. In the site investigated, however, the soil moisture units were along the border where the soil could be characterized as poorly drained, rather than very poorly drained, and thus water may have decreased somewhat more rapidly than is indicated by this last definition.

The soil moisture measurements charted in figure 8 provide some quantitative information on the actual drainage status in these three soils. In the moderately well-drained soil (Cardington), the soil moisture at six in. rarely remained at one-third atm for very long, even in May. However, internal drainage was impeded by the high clay content of the B, and in the upper horizons, saturation occurred for more extended periods in May and June. The lower B horizon at 24 in. remained saturated through June.

The imperfectly drained soil (Bennington) had a longer period in the spring when the upper layers were saturated as they received moisture from the slopes above. By late June or early July, conditions of soil moisture less than one-third atm were more common. The interesting thing noted here is that while the moisture at six in. remained high, the moisture at a 12-in. depth, where mottling is common, appears to have decreased more rapidly, even exceeding the moisture decrease at the same level in the better drained Cardington. This is probably the result of the high root density in this layer of the Bennington, which evidently counteracts the potentially more moist character of this soil. The most marked decrease in soil moisture at 24 in. did not occur until August, probably after roots had penetrated to this lower level.

The moisture in the poorly to very poorly drained Marengo soil was at or near field capacity (one-third atm), until it began drying out at the six in. level in July. This decrease in moisture through August appears to have been less rapid than in the soils at the higher sites, but by September it approached wilting percent level throughout the profile.

The observations made at these sites indicate some differences in the moisture status of the three soils; but, at least during the growing season, these differences are not as great as might be inferred from the definitions given in the Soil Survey Manual.

SUMMARY

1. A comparison of the soil environment is made, grading from a very poorly drained site, where beech is at its lower limits in a swamp forest association, to a moderately well-drained site dominated by a beech-maple association. Three soil types occur over this transition: Marengo silty clay loam in the depression, Bennington silt loam on the gentle lower slopes, and Cardington silt loam on the better drained low ridges and knolls.

2. On the Marengo, beech is represented by a low basal area, as it is only an occasional associate of the swamp forest community; on the Bennington, beech reaches its greatest basal area and is the only major shade-tolerant competitor; but on the Cardington, the basal area of beech is somewhat less and sugar maple becomes more important. Both the total basal area of all trees and the total number per 1,000 ft^2 decrease only slightly from the Marengo to the Bennington soil, and then decrease more markedly from the Bennington to the better drained Cardington silt loam.

3. The soil profile characteristics, chemical and physical properties, relative root density, and temperature and moisture regimes are described for each soil type, and related to the development of the three forest communities.

a) The small basal area of beech on the Marengo silty clay loam of the depressions is attributed largely to high early-season soil moisture and low porosity, which contribute to poor aeration of the soil, allowing development of only a shallow and small beech root system. During either a drought or an excessively wet year, these shallow-rooted beech are affected more adversely than other swamp forest species. As a result, the less shade-tolerant but deeper rooted swamp forest species are more abundant.

b) On the imperfectly drained Bennington silt loam, better aeration capacity and shorter periods of water saturation are largely responsible for a more extensive root system in beech, which penetrates into, but not generally beyond, the high and compact clay B horizon. Here beech is not so severely affected by extreme weather conditions. On this site it is better able to compete with the less shade-tolerant swamp forest species, and becomes better developed than on the other soils of the study area.

c) On the moderately well drained Cardington silt loam, the finer structure, greater porosity, and well drained conditions lead to relatively high aeration at greater depths and beech develops a still deeper root system which extends even below the high clay B horizon and increases slightly in density and size in the C layer. With more runoff and shorter periods of high soil moisture, wet seasons are not as limiting. With the deeper and larger root system, beech can better withstand drought, even though soil moisture may be lower than in the Marengo soil. The smaller total basal area and number of all trees on this well drained Cardington soil is thought to be a result of lower available soil moisture. Since sugar maple also does well on this better aerated site, it is a major competitor and further reduces the area available to beech.

4. It appears that during the two growing seasons studied, differences in moisture conditions were not as great as might be inferred from the standard definitions of the drainage classes for the three types. The soil moisture in the highly mottled B_{1g} of the Bennington shows a more marked decline due to the presence of many roots than does the soil moisture at the same depth in the better drained Cardington silt loam.

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MAGNESIAN HALOTRICHITE FROM VINTON COUNTY, OHIO

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During the Fall of 1956 and Spring of 1957, a study was made of acid waters issuing from abandoned coal mines located in the upper part of Sandy Run Valley tributary to Lake Hope (fig. 1). This study was part of a broader one of acid mine water pollution made under the direction of The Ohio State University Engineering Experiment Station. It was during this time that white efflorescences were found and that interest in their particular nature began. The following report is 1) a general description of the site geology where the mineral was found, 2) a description of the mineral and comparison with others of the general nature, and 3) notes on the origin of the mineral Halotrichite.

FIGURE 1. Location map of the northeast part of Brown Township, Vinton County. Arrow and dot indicate the location of the abandoned mine were the halotrichite was found.

Site Geology

In the watershed area of Lake Hope the surface is underlain by rocks of the Allegheny and the lower Conemaugh series of the Pennsylvanian system. In this area several coal and clay beds of commercial thickness occur, and in the upper part of Sandy Run Valley the Middle Kittanning coal has been extensively mined. The Lower Freeport sandstone overlies the coal. In this area its occurrence is massive and is associated with the overlying similar Upper Freeport sandstone. These form steep valley walls or cliff faces.

In some places undercutting of the Lower Freeport sandstone, by removal of the Middle Kittanning coal and clay and partly by removal of the lower portion of the sandstone, has produced hollows or overhang ledges. At the mineral

location the coal outcrop occurs beneath the overhanging ledge and two mine entries have been made into the coal (fig. 2). Water issues from one opening and some of it flows into other abandoned workings. On piles of loose material formed from mine refuse as well as spall material from the sandstone, a white efflorescent mineral was found.

Mineralogy

The Vinton County mineral (fig. 3) was first thought to be alunogen, a hydrated aluminum sulfate with the formula $Al_2(SO_4)_3 \cdot 18H_2O$. The mode of occurrence, fibrous habit, alumlike taste, water-solubility, and observable optical properties are all consistent with such an identity. Furthermore, a recently reported occurrence of alunogen under somewhat similar conditions in West Virginia would seem to support this tentative identification (Temple and Koehler, 1954). However, chemical analysis and x-ray diffraction data did not bear out this conclusion.

FIGURE 2. Site of halotrichite occurrence at opening of rock overhang near mine opening. White area in right foreground is a deposit of halotrichite lying on spall from the rock overhang.

The first suggestion that the mineral was not alunogen came from an examination of its x-ray diffractometer pattern as well as from concurrent chemical data. The x-ray data did not even approximately fit the data for alunogen, as recorded on card 1-0348 of the A.S.T.M. card file of x-ray diffraction data. Chemical analysis strongly suggested that the mineral might be a member of the pickeringite-halotrichite series, the end-member formulas of which are $MgAl_2(SO_4)_4 \cdot 22H_2O$ and $FeAl_2(SO_4)_4 \cdot 22H_2O$, respectively. Comparison of its x-ray diffraction pattern with that of pickeringite from New Mexico, and with recently published data for halotrichite from White Mountain, California (Baur and Sand, 1957) left little doubt that the Vinton County material was a member of this series. In figure 4 the patterns of pickeringite and halotrichite are practically undistinguishable, attesting to the difficulty of distinguishing between end-members or intermediate members of the series without resorting to chemical analysis. The correspondence of the

mineral alunogen with reagent-grade aluminum sulfate is also clearly shown. So-called alunogenite from West Virginia corresponds to the pickeringite and halotrichite patterns, rather than to alunogen.

In table 1 chemical analyses of the Ohio mineral and the California halotrichite are compared to the pure theoretical iron end-member of the series. The similarity between the last three columns is apparent. The analysis of the Vinton County material suggests that magnesia substitutes for a portion of the iron oxide; the mineral would, therefore, properly be called magnesian halotrichite.

The principal optical properties of pickeringite, halotrichite, and alunogen, as recorded in the widely-used determinative tables of Larsen and Berman (1934) are compared in table 2.

Because of the finely fibrous nature of these minerals, certain properties such as optic sign, which might serve to distinguish pickeringite-halotrichite members from alunogen, cannot readily be determined. Table 2 leaves little doubt as to

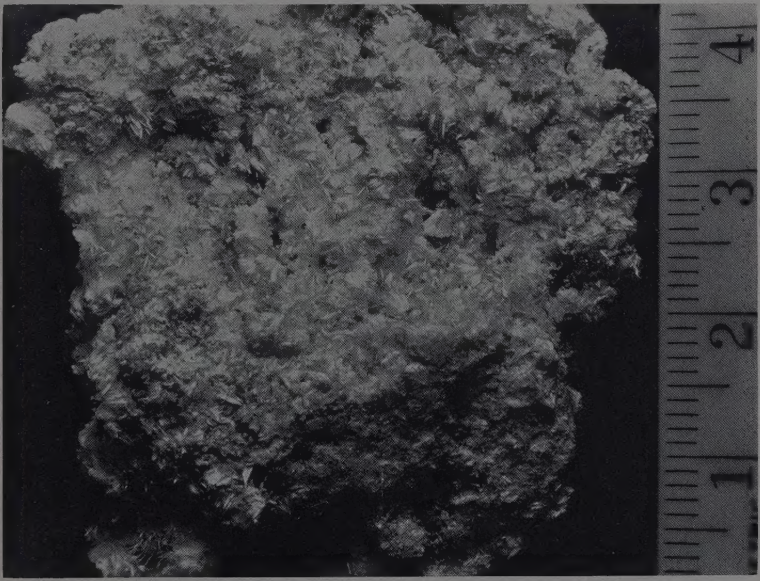

FIGURE 3. Detail of halotrichite mass showing fibrous nature.

the difficulties involved in conclusive distinction between these various minerals on the basis of optical properties alone. It is, therefore, highly probable that halotrichite and pickeringite are often erroneously identified as alunogen, particularly if the determination has relied primarily upon optical examination. At least three such instances are known to the authors. Thus, a sample from the United States National Museum labelled "alunogen" was demonstrated by x-ray diffraction to be a member of the pickeringite-halotrichite series. The "alunogenite" sample from West Virginia (fig. 4) is likewise a member of the series; so also is a sample from Nevada which had been microscopically identified as "alunogen." Northrup (1942) has observed that halotrichite is apparently exceedingly rare in the United States. He suggests, however, that it is perhaps more common than the records would indicate. Our experience would tend to substantiate this latter statement.

As a corollary to the above described occurrence, a coal core, stored in a basement for approximately four years, was examined. The conditions were not unlike those of some coal mines. Over much of the surface of this core was a deposit of feathery clusters, many of which had become detached and formed a fluffy aggregate between the core and the enclosing box. The deposit proved to be halotrichite. All of the cluster areas noted were points at which appeared small blebs of pyrite or marcasite about 1 mm by 5 mm in dimension. However, in a zone about 1 ft from the base of the coal, the site of a sulphide lens was noticed about 2 in. in thickness. At this place was an occurrence of melanterite, as nearly colorless transparent crystal fragments with a bluish green cast. That both minerals are formed under somewhat similar circumstances is interesting to note.

TABLE 1
Chemical composition

Chemical constituent	$MgAl_2(SO_4)_4 \cdot 22H_2O$ (Theoretical)	Vinton Co. Ohio	Halotrichite White Mountains California	$FeAl_2(SO_4)_4 \cdot 22H_2O$ (Theoretical)
MgO	4.69	2.7	——	——
FeO	——	5.9	6.8	8.07
MnO	——	0.4	——	——
CaO	——	0.4	——	——
Al_2O_3	11.87	12.3	12.0	11.45
SO_3	37.29	39.3	37.1	35.97
H_2O	46.15	38.8	43.8	44.51

TABLE 2
Optical properties

	Pickeringite	Halotrichite	Alunogen
Alpha	1.476	1.480	1.474
Beta	1.480	1.488	1.476
Gamma	1.483	1.490	1.483
Axial angle	Medium	Medium small	69°
Optic sign	Negative	Negative	Positive
Orientation	Y=b	Y=b	X=b
System and Habit	Z C=37° Mon. Fib.	Z C=38° Mon. Fib. C	Z C=42° Mon. Tab. (010) Fib. C
Color	Colorless, yellow, reddish	Colorless	White

Origin of Halotrichite

The source of the sulfate radical which makes up an essential part of the composition of halotrichite is a matter of considerable interest. Several possible origins have been proposed, and well-substantiated examples of each have been described. One proposed mode of origin involves volcanic action, the sulfate emanating from hot ascending gases or solutions associated with fumaroles or hot springs. Of such origin are the primary sulfates of Gila River, New Mexico, the hot spring deposits (Hayes, 1907) at Lassen Peak, California, and the solfataras near Naples, Italy.

A more common source of such sulfates is the oxidation of pyrite or marcasite disseminated through ore deposits, sedimentary rocks, or coal seams. An early view maintained that the oxidation of pyrite could not lead to the production

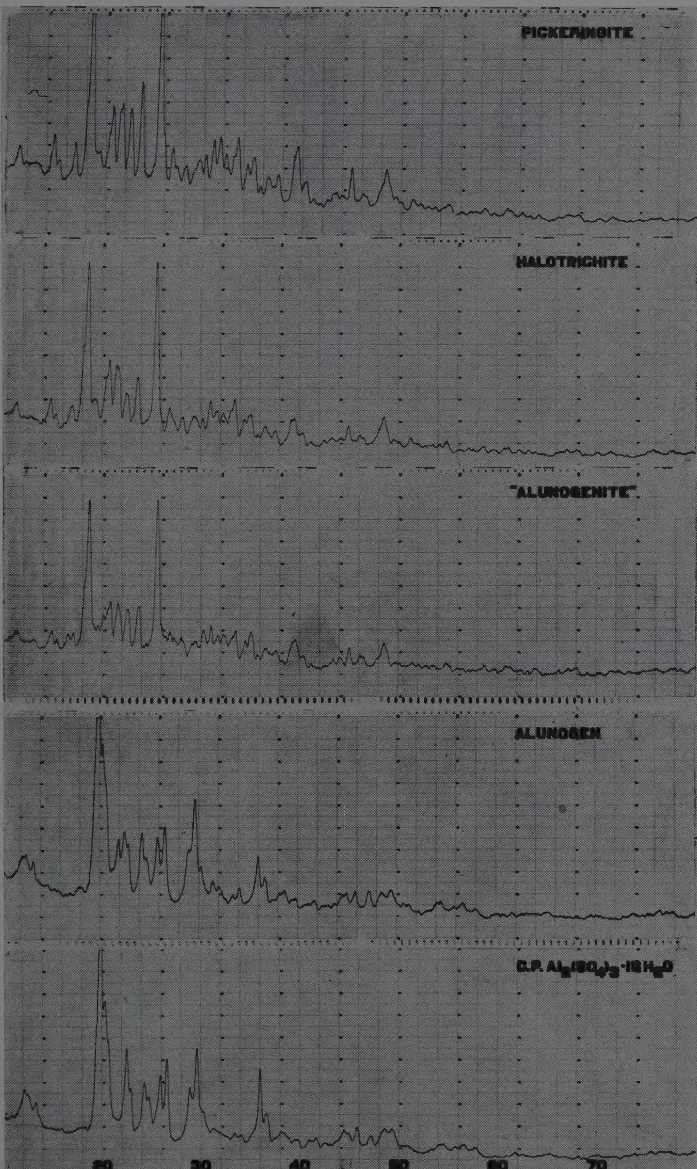

FIGURE 4. Comparison of x-ray diffractometer curves of pickeringite, halotrichite, "alunogenite," alunogen, cp $Al_2(SO_4)_3 \cdot 18H_2O$. Sources of material are listed in table 3.

of a ferrous-iron mineral such as halotrichite (Hayes, 1907). This view no longer appears to be tenable. Bandy (1938) attributes the halotrichite of the sulfate deposits of northern Chile to the direct oxidation of pyrite. Palache, Berman, and Frondel (1957) state that pickeringite and halotrichite are commonly formed as the products of weathering of pyritic rocks. Such weathering also furnishes ample iron, and there is no dearth of readily available alumina in the clay minerals and feldspars of the most common types of sedimentary and igneous rocks.

Whatever may be the ultimate source of the sulphate, there seems little doubt that the actual deposition of halotrichite is merely a matter of evaporation of an aqueous solution of ferrous and aluminum sulfates with or without an excess of sulphuric acid. Laboratory studies have demonstrated that such a process leads to its formation (Occleshaw, 1925). Capillary action draws such solutions through porous or fractured rock formations, and surface evaporation of the water causes the deposition of halotrichite. Favorite sites for the accumulation of such deposits

TABLE 3

Source of samples used for x-ray patterns

Specimen	Locality	Donor
Pickeringite	San Miguel Co., Colorado	U. S. Nat. Museum (No. 95410)
Halotrichite	Vinton Co., Ohio	Ohio Geological Survey
"Alunogenite"	Monongalia Co., W. Va.	W. Va. Experiment Sta.
Alunogen	Chacance, Chile	U. S. Nat. Museum (No. C 5576)
$Al_2(SO_4)_3 \cdot 18H_2O$	Chemical Reagent	Baker and Adamson

are the walls, ceilings, and floors of tunnels and caves, and the undercut sides of overhanging cliffs. Such sheltered places are conducive to the deposition of layers and encrustations of this highly soluble mineral while protecting it from the subsequent solvent action of rain water. Arid regions are, therefore, particularly favorable for such accumulations.

The genesis of the Vinton County halotrichite is believed to be somewhat as follows: the oxidation of pyritic material forms sulphate ions in place which may unite with iron, aluminum, and other ions to form the salt halotrichite. Upon dissolving, the compound may later reappear as a new deposit in protected and suitable sites as mentioned above. Mine waters, containing relatively high sulphuric acid and an assemblage of other ions from various sources, may conceivably be associated in a capillary situation to feed a desiccation surface of porous material and to allow the accumulation of the salt.

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